RIVETED BOILER JOINTS

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A TREATISE ON THE DESIGN AND FAILURES OF RIVETED BOILER JOINTS WITH NUMEROUS ORIGINAL DIAGRAMS ENABLING THE DESIGNER TO DESIGN ANY DESIRED JOINT WITHOUT CALCULATIONS

BY

S. F. JETER, B. S. M. E.

MEMBER OF BOILER CODE COMMITTEE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
CHIEF ENGINEER, THE HARTFORD STEAM BOILER INSPECTION AND INSURANCE COMPANY

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PREFACE

The exact determination of the theoretical strength of riveted boiler joints is doubtless not so important from the standpoint of safety as is generally credited, but the strength of the joints is necessarily considered in fixing the safe working pressure for a boiler. Since the cost of the material entering the shell of the usual type of fire tube boiler is a large part of the cost of all the material used in its construction, the importance of selecting the best form of joint is evident. In a large boiler, the difference in the cost of the shell material may vary one hundred dollars or more, depending on whether the best form of joint and arrangement of rivets is selected rather than one less suited to the purpose.

All previous practical attempts to aid the inspector or boiler designer in determining the strength of boiler joints, have been by the means of tables giving joint effieiencies. Since the methods used in calculating such tables were very laborious, the range covered did not extend beyond the arrangements most commonly required, consequently when the designer was forced by circumstances to consider a combination of rivet diameters and plate thicknesses out of the ordinary, the tables were without value, and since under such circumstances the designer had no practical experience to guide him, he was forced to resort to a cut-and-try method without any definite idea as to what rivet spacing might prove the best under the circumstances.

The diagrammatic method of determining joint strength is so simple, that there is no object in limiting the range of combinations of plate thicknesses and rivet diameters, and the diagrams in this book include all practical combinations. The diagrammatic method also has the advantage over tables of directly indicating the effect on the strength of the joint, of each proposed change in the design and also permits of the ready indication of the limiting rivet spacing, both minimum and maximum, so that the designer in attempting to attain a high efficiency is automatically warned when he begins to approach a spacing of rivets that will be either too wide to permit proper calking or so close as to produce interference in driving the rivets.

The treatment of the design of joints of maximum efficiency used in boiler construction is original, and probably presents the subject in a more usable form than can be found elsewhere.

The detailed methods of calculating joint efficiencies, as given in the first chapters, are intended for the boiler inspector or student, or for the engineer who is qualifying himself as a boiler inspector and who desires to understand the first principles involved in estimating the strength of the usual forms of joints adapted to boiler construction.

While the treatment of riveted joints in this book is primarily intended for those interested in boiler construction, the principles of joint efficiency as explained, apply with equal force to riveted joints for structural work and may, with profit, be used by the structural engineer.

An interesting fact, which, though doubtless understood by mathematicians who have worked on the problems connected with the strength of riveted joints, but not generally understood, is, that by fixing the tensile and crushing strength of the plate material, the possible maximum efficiency that may be attained with each of the different types of joints is fixed; that is, with these two factors entering the calculation of the strength of riveted joints fixed, the highest efficiency that may be obtained with any given arrangement of rivets does not vary.

HARTFORD, CONN., *January*, 1917. THE AUTHOR.

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RIVETED BOILER JOINTS

CHAPTER I

METHODS OF JOINT FAILURE

Riveted-joint failures are failures either of the plate or of the rivets, or failures that involve a combination of these two joint elements. There are two classes of failures: Those intended to be provided against in the design of the joint, and those which enter the usual calculations made to determine the strength of such joints. The consideration of the different methods of failure will be taken up in the order named.

FAILURES PROVIDED AGAINST IN DESIGN

Breaking of Rivets Through Edge of Plate.—It is evident that in any riveted joint, if the rivet holes adjacent to the edge of the plate

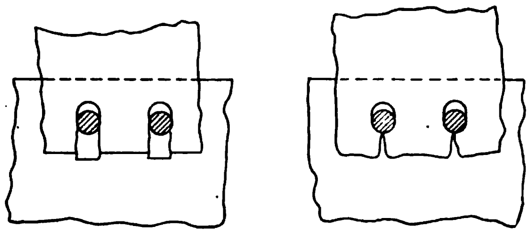


FIG. 1.—Joint failure by breaking through at edge of plate.

are too close to that edge, failure may occur by the rivets pulling out through the edge before the full shearing strength of the rivets is developed. Failure from this cause may be produced by either method shown in Fig. 1. No definite basis upon which to calculate the probability of failure by such methods can be derived, but it has been demonstrated in tests made on riveted joints, that if the distance from the edge of the plate to the rivet hole be made equal to the rivet diameter, this method of failure is not probable. The distance of the rivet hole from the edge of the plate is usually taken as the distance from the center of the hole. The center of the hole should be not less than one and a half rivet diameters from the edge of the plate. It would be assumed at once in studying this problem, that the plate thickness must necessarily be a factor in determining whether the method of failure illustrated in Fig. 1 is likely to occur. The plate thickness is a controlling factor. The amount of lap described above would, no doubt, be too small to apply where there were greater differences between the thicknesses of plate and rivet diameters than usual in boiler joints.

The plate thickness in relation to the rivet diameter is cared for in estimating the strength of another kind of joint failure, described presently, namely, the crushing strength of the plate.

Effect on Joint Strength of Distance Between Rows of Rivets.—Another method of failure supposed to be cared for in the design is that indicated in Fig. 2. This is a failure along diagonal lines instead of along lines through the rivet holes, parallel to the length of the joint. This method of failure is, of course, dependent on the distance

between the rows of rivet holes, as dimension *a*, Fig. 2. This distance is referred to as *back pitch*. If the plate material that would be separated by such a failure was as strong as that to be separated on a line lengthwise of the joint, the solution of the problem to provide sufficient material along the diagonal lines would be comparatively simple, for it would be necessary to have only as much or more material along the diagonal lines as along the longitudinal lines to insure that the strength against failure along the diagonal lines would be at least as great as that along the longitudinal lines. However, because the material used for boiler plates is not so strong in shear as in tension, the diagonal sections are weaker than longitudinal sections of equal area. Another factor that would enter the problem, if it could be solved with accuracy, is the effect of the longitudinal stress due to the pressure tending to rupture the shell of a boiler in an endwise direction. This factor will be left out of the discussion because of the uncertainty of its effect in usual boiler structures. For example, the actual endwise load produced by pressure in a boiler where tubes or braces hold the heads together, is problematical, and where no such members complicate the problem of determining what the actual endwise load is, the distribution of the stresses along the longitudinal seam of the shell due to this load is uncertain because the lapping of the plates or the placing of butt straps along the seams produces a rigid area along the seams, and the distribution of the stresses in the shell is correspondingly effected.

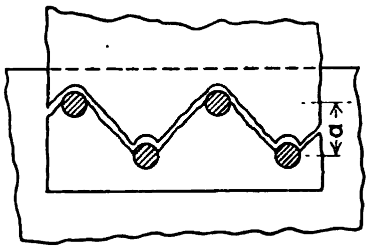


FIG. 2.—Joint failure where back pitch is not sufficient.

It has been demonstrated by tests for tensile strength of boiler joints that the cross-section of material along diagonal lines between the rivet holes may be required to be in excess of the cross-section along longitudinal lines by as much as 35 per cent. to insure that failure would occur along the longitudinal line; but it is evident that the angularity of the section is a governing factor.

In 1915, J. W. F. Macdonald made a series of tests at the Watertown arsenal to determine the effect on the strength of the joint of angularity of the net section between rivet holes. He found that when the strength of a net section at 90 deg. to the direction of the force applied to separate the plate was assumed to be 100 per cent., if the net section was placed at an angle of 10 deg. to this position, that the percentage increase in the area of section required to maintain the original strength was about 7 per cent.; for a 20-deg. change in position the increase required was about 13 per cent.; for a 30-deg. change, about 20 per cent.; and for 40-deg. change, about 26 per cent. Where the angularity between a line in the direction of the length of a joint and the diagonals between the rivet holes is considerable, say 40 deg. or more, it is not difficult to secure the additional metal necessary in the diagonal sections to make them as strong as the longitudinal sections, but where this angularity is small, as in the case of the outer rows of rivets in butt-strap joints of the type using straps of unequal widths, the joints become too wide if it is attempted to place additional metal in the diagonal sections, or even to make them of area equal to the longitudinal sections.

It is important to keep joints to a reasonable width, and therefore it is best to ignore the requirements for back pitch where the angularity between the diagonal sections and a line parallel with the direction of the seam is less than 30 deg., and merely place the rows of rivets a reasonable distance apart—not less than twice the diameter of the rivet holes. While this design will cause the weakest section of the joint to be of less strength than the section that is usually calculated, the reduction in the actual strength will no doubt be compensated for by the increase in the average strength and thickness of the plate over the usual assumed values taken in calculations for strength, as explained in Chapter V on "Boiler-plate Material," and the actual strength of the shell to which the joint is applied will no doubt be equal to the calculated strength.

The Boiler Code of the American Society of Mechanical Engineers gives 20 per cent. as the required increase in area in diagonal sections

over the longitudinal, and this value is evidently correct for the usual angularity met with in boiler seams under the conditions considered in the Code. For an arrangement of rivets as shown in Fig. 3, which illustrates the rivet arrangement in a lap or in a butt-strap joint with straps of equal width, the Code requirements are met when the distance between the rows of rivets or x, is equal to or greater than $\sqrt{0.11P^2 + 0.48Pd + 0.16d^2}$. That is, $2a$ is then 20 per cent. or more in excess of b. Where the arrangement of rivets is as illustrated in Fig. 4, the Code requirement for a to be at least 20 per cent. in excess of b, are met when y is equal to or greater than $\sqrt{0.0275P^2 + 0.6Pd + d^2}$. This is the usual arrangement of rivets in a triple-riveted joint with

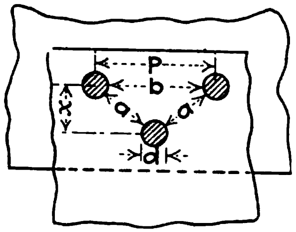


FIG. 3.—Requirements for back pitch, rivets spaced the same in each row.

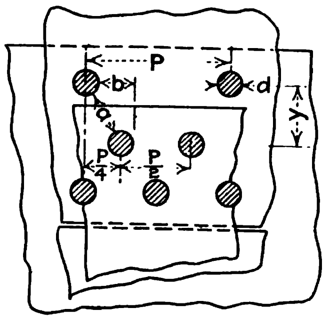


FIG. 4.—Requirements for back pitch, for triple-riveted joint.

straps of unequal width. For quadruple-riveted joints of this character, where the riveting is arranged as in Fig. 5, the Code requirements are met by making w equal to or greater than

$$\sqrt{0.006875P^2 + 0.3Pd + d^2}.$$

Note that the value of w is one-half the value of y as found above, because the value of P in the latter case is twice as great as in the former. The distance between the outer and second row of rivets, z, as in Fig. 5, does not come under Code requirements for back pitch. However, if it is desired that this dimension be of sufficient magnitude to insure that the sum of the diagonal sections between the rivet holes in the outer and in the second rows will be at least equal to the length of the net section between the rivet holes in the outer row, this requirement will be met when z, Fig. 5, is equal to or greater than $\sqrt{0.5Pd + 0.25d^2}$. The Code, in addition to the above requirements as to the length of diagonal section between rivet holes, also specifies that the distance between the rows of rivets shall not be less than

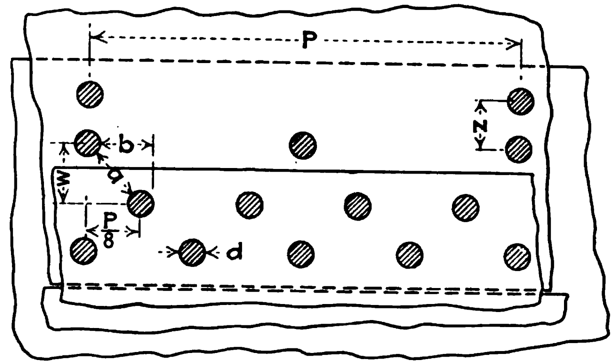


FIG. 5.—Requirements for back pitch, for quadruple-riveted joint.

two rivet diameters, so that if the required length of diagonal section permits a closer spacing than this, then the requirement of a minimum spacing of two rivet diameters would govern.

FAILURES CONSIDERED IN CALCULATIONS FOR STRENGTH OF JOINTS

Shear of Rivets.—In a simple lap-riveted joint, as in Fig. 6, it is evident that when a force is applied in the direction indicated by the arrows, if the plate is sufficiently strong to resist being torn apart, the result would be as shown in Fig. 7. If there were no tendency for the plates to bend, the rivets would be placed in true shear and their strength would be represented by the shearing value per square inch of the material of which they were made multiplied by the number of

square inches of the rivet material separated. If instead of lapping the two plates to be joined, as in Fig. 6, they are butted together and a strap placed on each side, as in Fig. 8, it is evident that to separate the joint, as in Fig. 9, it would be necessary to shear twice the rivet area, as

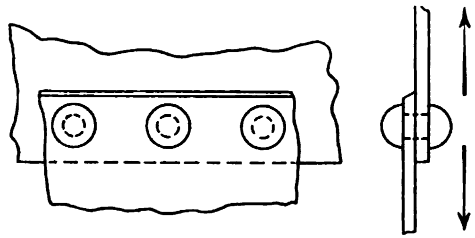


FIG. 6.—Lap joint.

with Fig. 6, assuming that the rivets are of the same size in each case. If the rivet material was in true shear in each case the strength of Fig. 6 would be one-half that of Fig. 8, as far as the strength of the rivets was concerned, but where the plates are thin with respect to the rivet

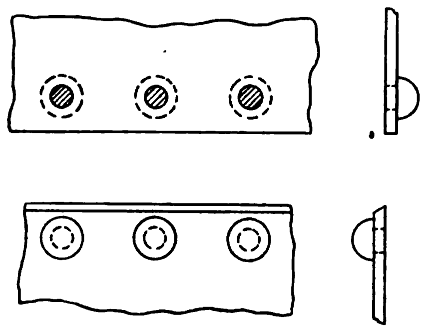


FIG. 7.—Shearing of rivets, single shear.

diameters, Fig. 6 might assume a shape like Fig. 10 before the rivets would shear. This would tend to indicate a higher shearing value for the rivet material because of its being partly in tension. On account of this supposed bending action, it has been customary to assign a higher shearing value per inch of material sheared in the case of lap joints than with double-strap joints, as Fig. 8.

An analysis of the experiments on riveted joints would seem to

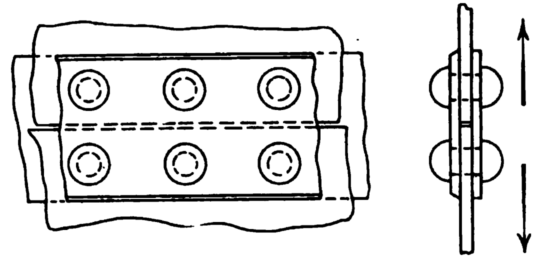


FIG. 8.—Double-strapped butt joint.

indicate that the real reason why the shearing value of rivet material in single shear appears to be higher than that in double shear is that no account was taken of the bearing pressure on the rivets. This is now

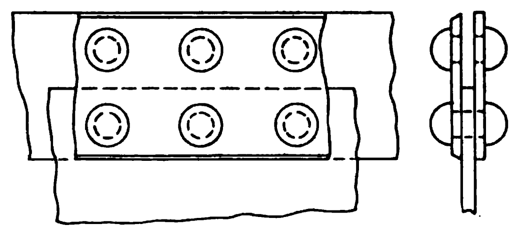


FIG. 9.—Shearing of rivets, double shear.

taken into account in figuring the strength of boiler joints. Assuming the shearing strength of rivet material subjected to single shear at one-half its value when subjected to double shear tends to simplify the

calculation of the strength of riveted joints. The Boiler Code makes no distinction in the shearing value per square inch of material separated, whether in single or in double shear, and in this book the shearing strength of a rivet in single shear will be assumed to be one-half of its strength in double shear, and unless otherwise specified, the shearing strength per square inch of sheared material will be taken at 44,000 lb.

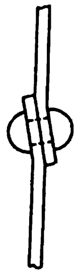


FIG. 10.—Change in shape under stress.

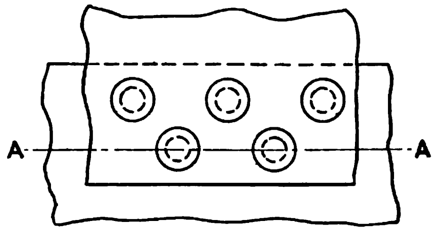


FIG. 11.—Double-riveted lap joint.

Breaking of the Net Section of Plate.—It is evident that to shear all rivets in a joint the net section of the plate between the rivet holes in the outer row of the joint must be stronger than the rivets; or conversely, if the shearing strength of the rivets is greater than the strength of this section of the plate, the plate will fail. For example, in Fig. 11, if the area of rivet section in shear multiplied by the shearing strength of the rivet material is greater than the net section of plate along the line AA multiplied by the strength of the plate material in tension, it is evident that the plate will fail along AA, by tearing apart. In more complicated joints, as will be shown presently, failure may occur by a combination of plate failure and rivet shear. The strength of the net section of the plate between rivet holes is calculated as the area of the metal to be separated multiplied by the tensile strength stamped on the plate, and while this is the usual and only way to calculate the strength of the net section of a joint, it is not likely that this calculated strength would be the actual strength, for as has been explained in Chapter V, the stamped tensile strength on the plate is likely to be different from the actual tensile strength of some portions of the plate; also the reinforcing effect on the section between the rivet holes may make an appreciable difference in the tested strength, the same as in the old form of test specimen, page 26, particularly if the rivet holes are relatively close to one another.

Crushing Strength of Material.—From what has been said about the shearing strength of rivets and strength of the net section of the plate between the rivet holes, it is evident that a joint might be designed with a given thickness of plate so that these two factors of joint strength would counterbalance, that is, so that the joint would be as likely to

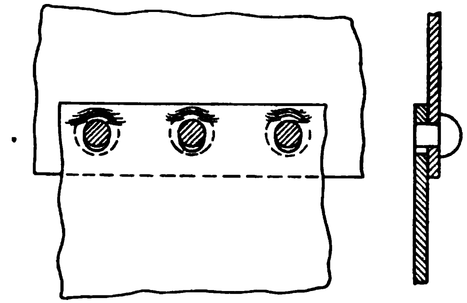


FIG. 12.—Plate crushing in front of rivets.

fail by either method. With a single plate thickness the pitch required for equality in these two factors would vary with the size of rivets, that is, the longer the pitch the larger the rivet diameter required to maintain the equality in strength between the shear of the rivets and tensile strength of the net section of plate.

The bearing pressure between plates and rivets is based on the thickness of the plate and the diameter of the rivets. For example, with 1-in. rivets and ½-in. plate, the bearing surface would be the projected area of contact between the plate and the rivet or $1 \times \frac{1}{2} = 0.5$ sq. in. As the rivet area exposed to shearing varies as the square of the diameter, and as the bearing surface between the rivets and the plate varies

directly as the rivet diameter, as the rivet size increases for a given plate thickness the bearing pressure will become greater and greater, and a point will finally be reached where the plate material can no longer withstand the crushing load placed upon it, and it may fail in a manner illustrated in Fig. 12. The plate failure shown in Fig. 12 should not be confused with the tearing out of the rivets through the edge of the plate owing to insufficient lap, as has been previously explained and illustrated in Fig. 1, for the crushing of the plate is assumed to take place with a more or less fixed maximum pressure between the surfaces without regard to the distance from the rivet hole to the edge of the plate, provided that this distance is at least one and one-half rivet diameters.

The crushing strength of plate, as indicated by tests of boiler joints, is not so constant a quantity as the shearing strength of rivets or the tensile strength of plate. A value of 95,000 lb. per square inch of bearing surface has been generally accepted as correct to represent the resistance of steel plate to crushing. For the crushing resistance of material to become a factor in joint failure, it is not necessary that the plate alone be concerned, for it was found by the committee of research on riveted joints of the Institute of Mechanical Engineers (English), who carried on many experiments to determine the factors controlling the strength of riveted joints, that bearing pressures of 100,000 lb. or more would cause the rivets to shear at a lower value than was known to represent their true shearing resistance at more conservative bearing pressures. The failure of the rivets under these conditions was an indication of excessive bearing pressure, rather than of a low shearing resistance. To the student the crushing strength as a determining factor for joint strength is apparently the most difficult to grasp of the three methods of failure, and it may be well to give a numerical example to further explain the subject. If a single-riveted lap joint, as in Fig. 6, was of the following proportions: 3 in. pitch, 1¼ in. rivet holes, and 9/16 in. plate; and the tensile strength of the plate and shearing strength of rivets were 55,000 lb. and 44,000 lb. respectively, the tendency to shear the rivets or break the net section of plate between the rivet holes would be practically equal to each other, and the bearing pressure between the rivets and the plate would be about 55,000 lb. per square inch. If the same size rivets were used in a similar joint but spaced 17 in. apart and the plate thickness reduced to 1/16 in., the relation between the amount of rivet material in shear and the amount of plate material under tensile stress between the rivet holes would be the same as in the former case, but the pressure between the rivets and the plate would be nine times as great before either of the other two methods of failure could be assumed to occur. The bearing pressure would be about 495,000 lb. per square inch. It can be readily realized that long before this pressure was reached the plate in front of the rivets would crush as in Fig. 12.

CHAPTER II

TYPES OF BOILER JOINTS

It is intended only to treat what may be termed the standard types of boiler joints in this chapter, since a thorough understanding of how the strength of such standard joints may be obtained will enable the reader to estimate the strength of practically any type of joint used.

Single-riveted Lap Joint.—The simplest form of boiler joint and the one which was used for practically all purposes in boiler construction up to 30 or 40 years ago, is the single-riveted lap joint shown in Fig. 13.

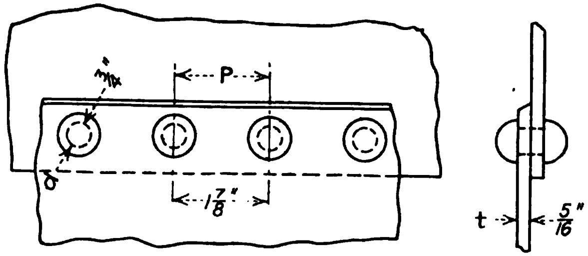


FIG. 13.—Single-riveted lap joint.

This joint gives the narrowest contact surface between the surfaces of the two joined plates, and for this reason it is largely used where it is required that a joint be exposed to a high temperature, such as the girth seams on a horizontal return-tubular boiler. The efficiency of this joint is not high, the maximum being 63.33 per cent., with a tensile and crushing strength of plate of 55,000 lb. and 95,000 lb. respectively.

Double-riveted Lap Joints.—The double-riveted lap joint, Fig. 14, was evidently evolved in attempting to improve the strength of the single-riveted joint. A considerably wider lap is required and it is consequently not so well suited for locations where it would be exposed to high temperatures, although it has been used occasionally for the girth seams of horizontal return-tubular boilers. The double-riveted lap joint is frequently used for girth seams, where greater strength or stiffness is required than is afforded by the single-riveted joint, and where such seams are not exposed to the direct furnace heat. The improvement in efficiency by double-riveting over single-riveting is

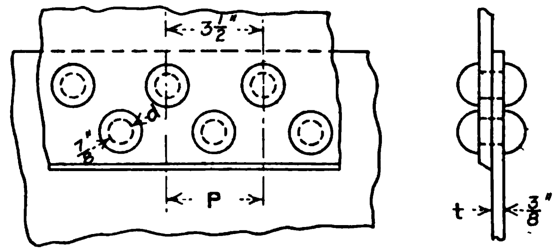


FIG. 14.—Double-riveted lap joint.

considerable as the maximum efficiency attainable with the double-riveted type, with the same tensile strength and crushing strength of material as before assumed is 77.5 per cent., or a gain of more than 14 per cent. While 77.5 per cent. is the maximum theoretically attainable efficiency for the double-riveted lap joint, if no attention need be paid to the spacing of the rivets along the calking edge, the maximum practical efficiency will be 72 or 73 per cent. The maximum theoretical efficiency for the single-riveted joint may be obtained for the

thinner plates if rivets of relatively large size are used, so that the actual difference in the strength of practical joints of the two types is not so great as the difference in the maximum theoretical efficiencies would indicate.

The double-riveted lap joint was the one used for practically all longitudinal boiler seams up to 25 years ago, and it is largely used for this purpose today, but it is being rapidly superseded by the various types of butt joints on account of the tendency of the lap joint to crack after considerable use. Such cracks are so located that their formation may not be readily detected; they often result in the explosion of the boiler.

Triple-riveted Lap Joint.—The triple-riveted lap joint, Fig. 15, is sometimes used to secure a joint of the lap type, of higher efficiency

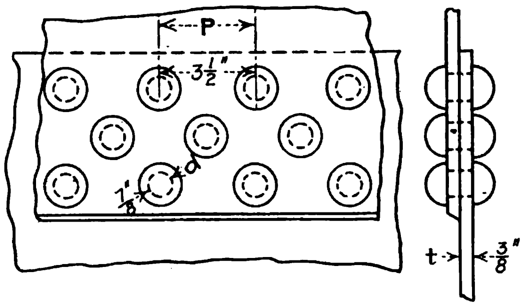


Fig. 15.—Triple-riveted lap joint.

than the single- or double-riveted joints. The use of this joint is not common, for while the maximum efficiency that may be theoretically attained is 83.8 per cent. using the same tensile and crushing values as before, the pitch of rivets required to approach this maximum efficiency is beyond the range that will produce a calkable joint, and therefore the full efficiency of the joint cannot be realized. The practical maximum efficiency that may be secured by the use of the triple-riveted lap joint is about 75 per cent., and the gain in efficiency over the double-riveted lap joint is therefore only 2 to 3 per cent.

It is possible with the triple-riveted joint to use rivets of smaller diameter with a given plate thickness and maintain a higher joint efficiency than with the double-riveted joint. With thicker plates it

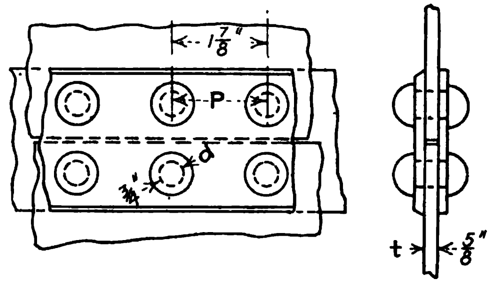


Fig. 16.—Single-riveted butt joint, straps of equal width.

is therefore possible to secure a high efficiency with this type of joint, without exceeding the rivet driving capacity of the usual boiler shop.

Butt Joint with Equal-width Straps.—Butt joints with straps of equal width are used more commonly abroad than in the United

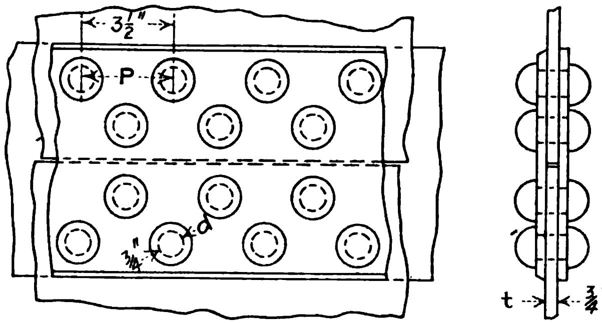


Fig. 17.—Double-riveted butt joint, straps of equal width.

States. The three kinds of this type of joint, single-, double- and the triple-riveted, are shown in Figs. 16, 17 and 18. The maximum efficiencies that may be attained by the use of these joints are the same

as for the lap joints with similar riveting, that is 63.3, 77.5 and 83.8 per cent. The relation between the plate thickness and the rivet diameters for the lap joints and the butt joints to secure maximum efficiency is very different, for with given dimensions for spacing and diameter of rivets, the same efficiency is obtained in each type when the plate thickness in the butt joint is twice that in the lap joint. This makes possible joints of the butt type that more nearly approach the theoretical maximum efficiency without requiring rivets of excessive size. While the efficiencies of butt joints with straps of equal width are not so high as can be obtained with butt joints with straps of unequal width, they have the advantage of being narrow and, where the longitudinal seams are likely to interfere with the location of brackets or other attachments, this feature is important.

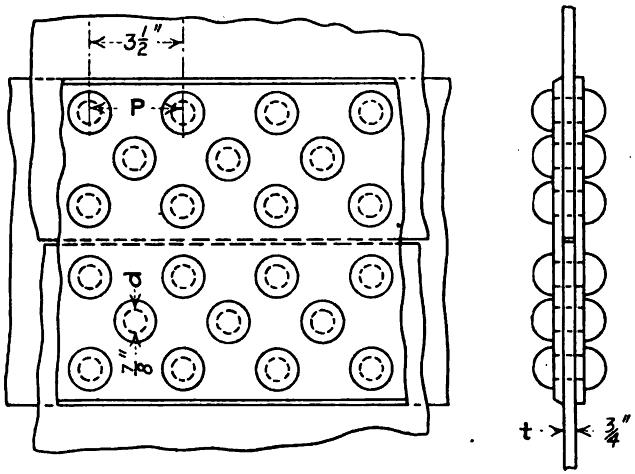


FIG. 18.—Triple-riveted butt joint, straps of equal width.

Double-riveted Butt-strap Joint, Straps of Unequal Width.—The form of butt-strap joint commonly used in the United States has butt straps of unequal width; such a joint of the double-riveted type is shown in Fig. 19. It is evident that since the rivets in the outer row of this joint are beyond the calking edge, their spacing is not determined by the necessity of presenting an edge that may be calked, except as the spacing of the rivets along the inner row may be governed by the spacing of those in the outer row. The maximum efficiency possible with this joint is 83.8 per cent., the same as for the triple-riveted lap joint. But the spacing of the rivets in the butt joint may be such that the maximum theoretical efficiency may be attained or closely approached where plates of moderate thickness are used, without spacing the rivets along the calking edge too far apart to permit of proper calking. Because of the relatively high efficiency available with practical rivet spacing, this joint is used where a narrow joint is required or where a higher efficiency that might be attained with a more complicated form of joint is not required. While it is possible to about reach the maximum theoretical efficiency with the thinner plates by the use of this type of joint, if the proper relation between the rivet diameter, plate thickness and rivet spacing is not maintained, the efficiency will fall off very rapidly, and it is not uncommon to find such joints which are poorly designed.

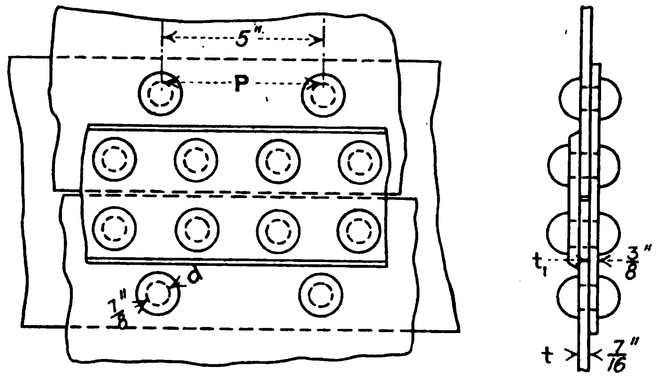


FIG. 19.—Double-riveted butt joint, straps of different widths.

Triple-riveted Butt-strap Joint, Straps of Unequal Width.—Until recent years, the triple-riveted butt-strap joint of this type was most

used in boiler work where maximum joint efficiency was desirable. This joint is shown in Fig. 20, and it will be noted that its general characteristics are the same as those of the double-riveted joint of this type—a single row of rivets on either side of the joint engaging the inner strap. There are two rows of rivets which pass through the two straps, giving a greater shearing resistance. The maximum efficiency with this type of joint, if the tensile and crushing strengths are as before, is 89.6 per cent. While it is not possible to design prac-

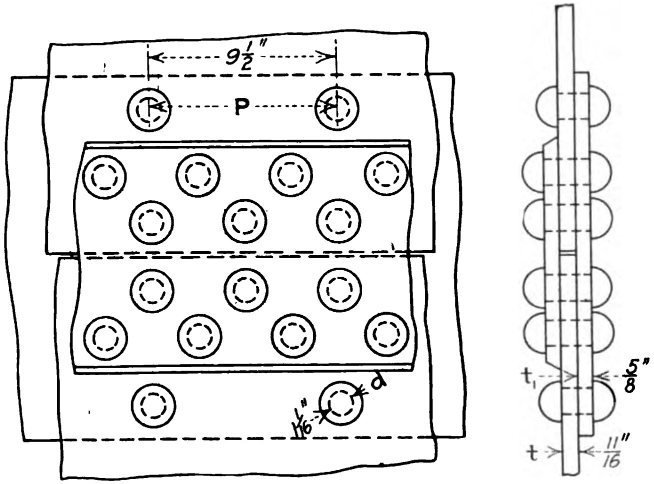


FIG. 20.—Triple-riveted butt joint, straps of different widths.

tical joints of this type that will show the maximum theoretical efficiency, by selecting the proper size rivets in relation to the plate thickness, one can secure efficiencies of 88 per cent. with plates of considerable thickness. Of course, this joint is wide, and if needed, the desirable features of a narrow joint must be sacrificed for the added strength which it affords.

Quadruple-riveted Butt-strap Joint, Straps of Unequal Width.—This type of joint is illustrated in Fig. 21, and it will be seen that it is the same as the triple-riveted joint, except that an additional row of rivets has been placed on the outside, the inner strap being extended in width to engage these rivets. This type of joint represents about the maximum of strength for the purpose of boiler design. The maximum efficiency of such a joint, with the same values for plate strength as assumed for the other joints, is 95 per cent., and working efficiencies of 94 per cent. are easily obtained.

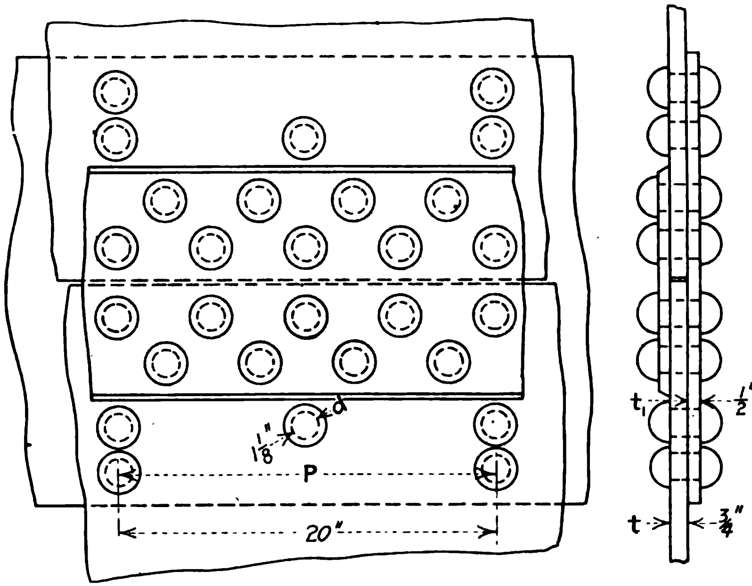


FIG. 21.—Quadruple-riveted butt joint, straps of different widths.

Quintuple-riveted Butt-strap Joint, Straps of Unequal Width.—Although rarely used in boiler work, the quintuple-riveted joint, Fig. 22, represents an advance in joint efficiency over the quadruple-riveted joint. The maximum efficiency of this joint is 97.54 per cent., when the strength of the plate is as has been previously assumed, and this theoretical efficiency can be closely approached with joints of

practical dimensions for the thinner plates. The objection to the use of this joint in boiler work is its width, but it is particularly adapted for tank work of large size, where it is desired to economize in material. It is possible to carry the principle of the butt-strap joint with straps of unequal width to include sextuple and even higher rivet combinations, but they are not adapted for boilers, and are little used in tank construction.

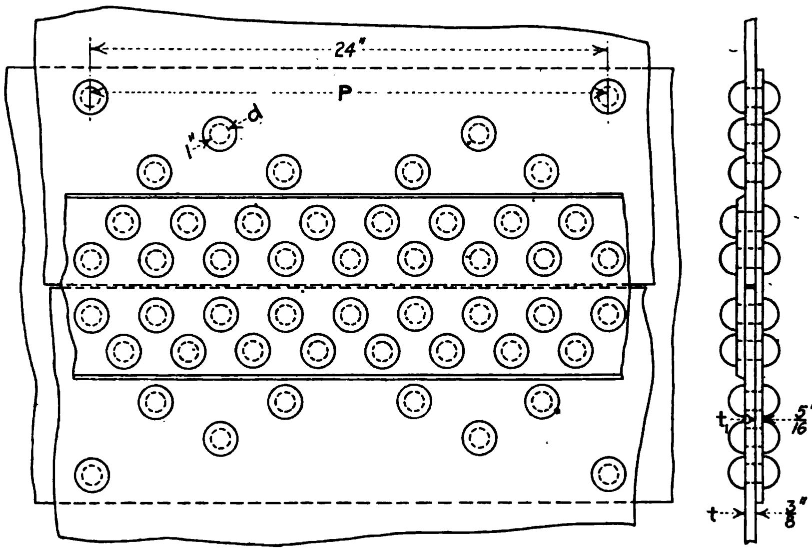


FIG. 22.—Quintriple-riveted butt joint, straps of different widths.

The Sawtooth Joint.—The arrangement of rivets shown in Fig. 23 is most frequently used for the sawtooth joint. Where the crushing strength and the tensile strength of the plate is 95,000 and 55,000 lb. per square inch respectively, the maximum theoretical efficiency that may be secured with this arrangement of rivets is 93.96 per cent. While this is lower than may be obtained with the usual form of quadruple-riveted joint with straps of unequal widths, owing to the smaller rivet required for the sawtooth joint, a practical joint of this type for thick plate may be stronger than the usual quadruple-riveted type. This is an advantage where provisions are lacking for driving rivets of sufficient size to secure the best results with the quadruple-riveted form, employing straps of unequal width.

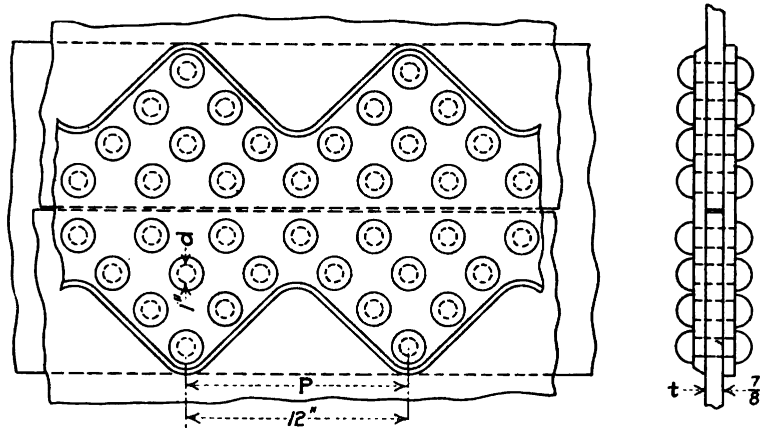


FIG. 23.—Sawtooth joint.

Single-strapped Joints.—It is customary to make butt joints using a single strap on the outside of the shell, as with digesters, where a lining is to be applied, or in vessels where stirring paddles are required to revolve in close proximity to the shell. Here the heads of the rivets on the inside of the vessel are countersunk to present a smooth surface. The strength of all single-strapped joints is the same as that for similarly designed lap-riveted joints, if the straps are of equal or greater thickness than the plate, except that with countersunk rivets, the weakening effect on the net section of plate between the rivet holes by countersinking must be taken into account.

The Locomotive Joint.—A joint made with a single strap but which is now little used is termed the locomotive joint and is shown in Fig. 24. It received this name because at one time it was in common

use in locomotive construction. The joint is merely a double-riveted

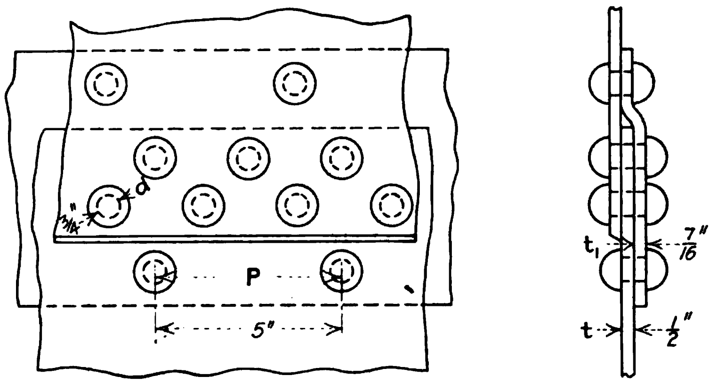


FIG. 24.—Locomotive joint.

lap joint with an inside strap added. A common criticism of the joint is that the strap would bend where it was fitted down over the inner lapping plate and fail to develop the full strength of the outer row of rivets on that side of the joint. However, extensive tests of this joint (see *Power*, Nov. 24, 1908, p. 866) seem to indicate that this criticism is not justified unless the rivets are relatively large for the strap thickness used.

The theoretical maximum efficiency for this joint is the same as for the triple-riveted butt joint with straps of unequal width, namely, 89.6 per cent., when the crushing and tensile strength of the plate is the same as assumed for other joints. This construction is peculiarly adapted for use in strengthening a lap joint where it is found to be weak for the pressure desired. It is obvious that none of the butt-strapped seams can be used where they would be exposed to the furnace heat, but the single strapping of girth seams of the steam drums of water-tube boilers is fairly common practice, where these seams are not exposed to high temperatures.

CHAPTER III

EFFICIENCIES OF BOILER JOINTS

Efficiency of a joint may be defined as the ratio of the strength of the joint to that of the solid plate, that is, if the strength of the joint is divided by the strength of the solid plate, the result will be the joint efficiency. It is usual in boiler joints to take the shortest length of the joint that will form a repeating section, or as it is usually termed

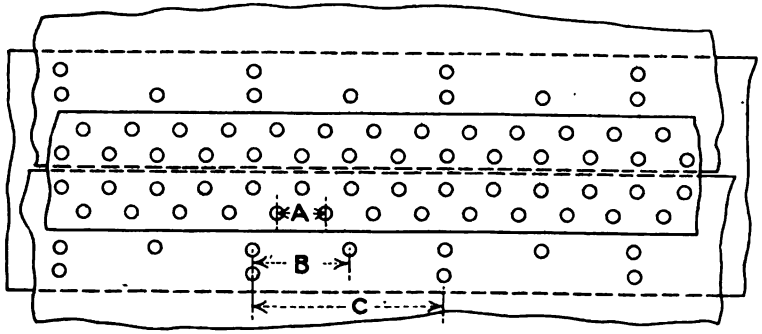


FIG. 25.—Unit section of joint.

a "unit section," for it is evident that the efficiency of such a section will represent the efficiency of the entire joint. For example, in Fig. 25, A would be a repeating section as far as the rivets through the two straps were concerned, but this would not be so if the whole width of the joint were considered. Section B would be a repeating section, except that the successive sections would be right and left hand, as far as rivets in the outer row were concerned. It is customary to consider a unit section, as section C, in calculating the efficiency of a joint, such as Fig. 25. It is plain that by repeating this section over and over, any length joint of the same type may be secured, so that section C represents all the characteristics of a joint of this kind no matter what its length. Practical boiler joints rarely consist of true unit sections throughout their length because it is usually necessary to modify the layout near the ends of the joint to obtain a proper arrangement of rivets at these points, but it is not usual or necessary to give attention to such modifications in calculating the strength of the joints.

Notation.—The following notation will be adhered to in reference to the calculation of the strength of riveted joints:

T = the tensile strength of plate per square inch, in pounds, or 55,000 lb.[1]

S = the shearing strength of rivet material per square inch, in pounds, where subjected to single shear, or 44,000 lb.

$2S$ = the shearing strength of rivet material per square inch, in pounds, where subjected to double shear, or 88,000 lb.

C = the crushing strength of plate per square inch, in pounds, the projected area of contact between the plate and rivets being used, and 95,000 lb. representing this value.

P = the pitch of rivets, or a unit section length of joint, in inches.

d = the driven diameter of rivets, or the diameter of rivet hole, in inches.

t = the thickness of the plate, in inches.

t_1 = the thickness of butt straps, in inches.

Efficiency of Single-riveted Lap Joints.—To calculate the efficiency

[1] The Boiler Code of the American Society of Mechanical Engineers states that the highest tensile strength allowed to be stamped on boiler plate is 55,000 lb.

of a single-riveted lap joint as Fig. 13, three methods of possible failure are to be considered: First, the breaking of the net section of the plate between the rivet holes; second, the shearing of the rivets; and third, the crushing of the plate in front of the rivets. It will be seen by reference to Fig. 13, that in a unit section of length P, the cross-sectional area of the material to be separated in pulling the joint apart would be the distance between the rivet holes multiplied by the plate thickness, and this value is generally referred to as the net section. There would be one rivet to shear in the same length of joint, and also one rivet to act in crushing the plate. The strength of the solid plate is the distance between the centers of the rivets multiplied by the thickness of the plate and by the tensile strength of the plate. Using the numbered dimensions given in Fig. 13, the value of each of the three methods of failure in the order in which they are named above would be as follows:

Strength of net section between rivet holes $= (P - d)\,tT$ or $(1\frac{7}{8} - \frac{3}{4})\frac{5}{16} \times 55{,}000 = 19{,}335.94$ lb.

Shearing strength of rivets $= 0.7854d^2S$ or $0.7854(\frac{3}{4})^2 44{,}000 = 19{,}438.65$ lb.

Crushing strength of plate $= dtC$ or $\frac{3}{4} \times \frac{5}{16} \times 95{,}000 = 22{,}265.63$ lb.

Since the strength of the solid plate is PtT or $1\frac{7}{8} \times \frac{5}{16} \times 55{,}000 = 32{,}226.56$ lb., the efficiency of the joint would be $\frac{19{,}335.94}{32{,}226.56} \times 100$ or 60 per cent., because the resistance of the net section of the plate between the rivet holes is the weakest portion of the joint, and therefore, the determining factor in calculating its efficiency.

Efficiency of Double-riveted Lap Joints.—To calculate the efficiency of a double-riveted lap joint, Fig. 14, the procedure is as follows: The strength of the net section is to be obtained in the same way as for the single-riveted joint, for while there are two net sections that might be broken, both would have the same area. Assuming equal spacing and size of rivets, it will be seen that the strength of the rivets to resist shearing is twice as great in the case of the double-riveted joint as with the single-riveted one, and likewise the crushing strength is also doubled. The resisting strength for the three methods of failure, using the values given in Fig. 14, would be as follows:

Strength of the net section between rivet holes $= (P - d)tT$ or $(3\frac{1}{2} - \frac{7}{8})\frac{3}{8} \times 55{,}000 = 54{,}141$ lb.

Shearing strength of two rivets $= 2 \times 0.7854d^2S$ or $2 \times 0.7854 \times (\frac{7}{8})^2 44{,}000 = 52{,}916$ lb.

Crushing strength of the plate in front of two rivets $= 2tdC$ or $2 \times \frac{3}{8} \times \frac{7}{8} \times 95{,}000 = 62{,}344$ lb.

Strength of the solid plate, of length P equals PtT or $3\frac{1}{2} \times \frac{3}{8} \times 55{,}000 = 72{,}187$ lb. Since the shearing strength of the rivets represents the weakest part, the joint efficiency would equal $\frac{52{,}916}{72{,}187} \times 100$ or 73.3 per cent.

Efficiency of Triple-riveted Lap Joint.—Fig. 15 shows that the calculation of the strength of a triple-riveted lap joint is almost the same as for the double-riveted joint, for the two joints are the same, except for the addition of another row of rivets. If the size and spacing of the rivets and thickness of the plate were the same in two joints like Figs. 14 and 15, the strength of the net section of the plate would be the same in each joint; but the shearing strength and the crushing strength would be 50 per cent. greater for Fig. 15. It is obvious that the strength of the net section of plate along the center row of rivets in Fig. 15 does not have to be considered, because its strength must be the same as that of the two sections on either side, and for this section to break, the rivets in either of the outside rows would have to shear, and this shearing strength would be added to the strength of the net section between the rivet holes in the center row. Therefore, the section between the rivet holes in this row could not fail. Using the dimensions given in Fig. 15, which are the same as the similar dimensions in Fig. 14, the following results would be obtained for the strength of the joint as regards the different possible ways of failure:

Strength of the net section between rivet holes $= (P - d)tT$ or $(3\frac{1}{2} - \frac{7}{8})\frac{3}{8} \times 55{,}000 = 54{,}141$ lb.

Shearing strength of three rivets = $3 \times 0.7854d^2S$ or $3 \times 0.7854 (7/8)^2 \times 44{,}000 = 79{,}374$ lb.

Crushing strength of plate in front of three rivets = $3tdC$ or $3 \times 3/8 \times 7/8 \times 95{,}000 = 93{,}516$ lb.

Strength of the solid plate = PtT or $3\frac{1}{2} \times 3/8 \times 55{,}000 = 72{,}187$ lb.

By inspection of the above values; it is seen that the failure of the net section of the plate between the rivet holes, is very much the weakest portion of the joint, and the efficiency is therefore $\frac{54{,}141}{72{,}187} \times 100$ or 75 per cent.

Efficiency of Butt Joints with Double Straps of Equal Width.—The calculation of the efficiency of butt joints with straps of equal width, as illustrated in Figs. 16, 17 and 18, is identical with that of similarly riveted joints of the lap variety, except that the shearing values are doubled; in fact these joints, as far as the calculated efficiency is concerned, are the same as two lap joints placed together, where the thickness of the plate for the butt joint is made twice that for the corresponding lap joint. In the following illustrations of the calculation of the strength of butt joints with straps of equal width, the dimensions will be taken the same as for the previous lap joints considered, except that the plate thickness will be doubled, as shown in Figs. 16, 17 and 18.

Efficiency of Single-riveted Butt Joint, Double Straps of Equal Width.—In Fig. 16, the values for resistance to failure by the different possible methods would be as follows:

Strength of net section between rivet holes = $(P - d)tT$ or $(1\frac{7}{8} - 3/4)5/8 \times 55{,}000 = 38{,}671.88$ lb.

Shearing strength of one rivet in double shear = $0.7854d^2 2S$ or $0.7854(3/4)^2 88{,}000 = 38{,}877.30$ lb.

Crushing strength of plate in front of one rivet = dtC or $3/4 \times 5/8 \times 95{,}000 = 44{,}531.26$ lb.

Strength of the solid plate = PtT or $1\frac{7}{8} \times 5/8 \times 55{,}000 = 64{,}453.12$ lb.

Therefore the efficiency of the joint would be $\frac{38{,}671.88}{64{,}453.12} \times 100$ or 60 per cent.

Efficiency of Double-riveted Butt Joint with Double Straps of Equal Width.—In Fig. 17, the values for resistance to failure by the different possible methods would be:

Strength of net section between rivet holes = $(P - d)tT$ or $(3\frac{1}{2} - 7/8)3/4 \times 55{,}000 = 108{,}282$ lb.

Shearing strength of two rivets in double shear = $2 \times 0.7854d^2 2S$ or $2 \times 0.7854 \times (7/8)^2 88{,}000 = 105{,}832$ lb.

Crushing strength of plate in front of two rivets = $2tdC$ or $2 \times 3/4 \times 7/8 \times 95{,}000 = 124{,}688$ lb.

Strength of the solid plate = PtT or $3\frac{1}{2} \times 3/4 \times 55{,}000 = 144{,}374$ lb.

Therefore the efficiency of the joint would be $\frac{105{,}832}{144{,}374} \times 100$ or 73.3 per cent.

Efficiency of Triple-riveted Butt Joint with Double Straps of Equal Width.—In Fig. 18 the values for resistance to failure by the different possible methods would be:

Strength of net section between rivet holes = $(P - d)tT$ or $(3\frac{1}{2} - 7/8)3/4 \times 55{,}000 = 108{,}282$ lb.

Shearing strength of three rivets in double shear = $3 \times 0.7854d^2 2S$ or $3 \times 0.7854(7/8)^2 88{,}000 = 157{,}748$ lb.

Crushing strength of plate in front of three rivets = $3tdC$ or $3 \times 3/4 \times 7/8 \times 95{,}000 = 187{,}032$ lb.

Strength of the solid plate = PtT or $3\frac{1}{2} \times 3/4 \times 55{,}000 = 144{,}374$ lb.

Therefore the efficiency of the joint would be $\frac{108{,}282}{144{,}374} \times 100$ or 75 per cent.

Butt Joints with Straps of Unequal Width.—The previous types of joints for which the efficiencies have been calculated are of the simpler forms. For high efficiency joints with straps of unequal width, the cal-

culation of the efficiency is not so simple, although the problem is not so complicated as it is generally supposed or represented to be. Short cuts may be taken in calculating the strength of such joints, especially the quadruple- and quintuple-riveted ones, by making a general analysis of the problem to be solved. By using this method it will be found that to obtain the efficiency of such joints is almost as simple as determining efficiencies of lap joints.

Efficiency of Double-riveted Butt Joint with Double Straps of Unequal Width.—The student should be particularly attentive to the explanation of how to calculate the strength of this joint, for it is typical of all butt-strapped joints with straps of unequal width and represents in general the method used in estimating the strength of all such joints.

By examining Fig. 19 it will be seen that there are more combinations of possible joint failure presented than with the types of joints previously considered:

First, the outer net section between the rivet holes may fail. *Second,* the net section of plate between the rivet holes in the inner row may fail, and at the same time the rivets in the outer row shear. *Third,* the section of plate between the rivet holes in the inner row fail, and the plate or strap in front of the rivets in the outer row crush. *Fourth,* all the rivets may shear, those in the outer row single shearing and those of the inner row, double shearing. *Fifth,* the plate in front of the rivets in the inner row and the strap in front of the rivets in the outer row may fail by crushing. *Sixth,* the plate in front of the rivets in the inner row may crush and the rivets in the outer row shear.

A seventh method of failure, consisting of the shearing of the rivets in the inner row, and the crushing of the strap in front of the rivets in the outer row, might be considered, but it will be seen at once that such method of failure would be impossible because the inner rivets are in double shear, and if the plate thickness was sufficient to cause the shearing of the inner rivets, the rivets in the outer row must necessarily shear also, unless the strap thickness was less than one-half the plate thickness, which is not the case in commercial boiler joints.

While the third method of failure involving the crushing of the strap in front of the rivets in the outer row is represented in the formulas that follow for obtaining the efficiencies of joints of this type, it is done only to make the formulas complete, because this method of failure could never be the one governing the efficiency in a practical boiler joint. For the third method of failure to give a value for efficiency less than the first, when the value of C is 95,000 lb. and T 55,000 lb., the butt straps t_1 would have to be thinner than 57.89 per cent. of the plate thickness, or, if the value of T was 65,000 lb. and C 95,000 lb., the butt-strap thickness would have to be less than 68.42 per cent. of the plate thickness. Since in commercial boiler joints the strap thickness is usually 80 per cent. or more of the plate thickness to insure that the inner net section of the straps is stronger than the weakest method of plate or rivet failure, it is seen that there is no real need to consider the third method of failure.

Since the crushing strength of the plate in front of a rivet is equal to the diameter of the rivet multiplied by the plate thickness times the crushing strength of the plate material, the resistance per rivet to failure by crushing would therefore be tdC as before, and the strength of a rivet to resist shearing, where subjected to single shear would be $0.7854d^2S$. Making these two values equal each other would result as follows: $tdC = 0.7854d^2S$ or $t = 0.364d$, when C is 95,000 and S is 44,000.

Because any increase in the plate thickness would improve its ability to withstand crushing but would not effect the ability of the rivets to withstand shearing, any value of t greater than $0.364d$ would cause failure by shearing, and any value of t less than $0.364d$ would cause failure by crushing the plate or strap, if that was thinner than the plate. Since the resistance of the rivets in double shear is twice that in single shear there would be required a plate thickness of more than $t = 0.728d$ before the rivets in double shear would shear instead of causing the plate in front of them to crush. The first step, then, in cal-

culating the efficiency of a joint, as shown in Fig. 19, is to see if the strap thickness, or t_1 is greater or less than $0.364d$. Using the dimensions given in Fig. 19, results as follows: $0.364 \times 7/8 = 0.3185$, which is less than the strap thickness of $3/8$ in. Therefore, failure at the rivets in the outer row of the joint would be by shearing of the rivets rather than the crushing of the strap in front of these rivets. The calculation just made disposes of the third and fifth methods of failure.

From $0.728 \times 7/8 = 0.637$, it is seen that the $7/16$-in. plate, which is 0.4375 in., is thinner than would be required to cause the failure of the rivets in double shear by shearing, so that the failure along this row of rivets would be by the crushing of the plate, instead of double shearing the rivets. This calculation disposes of the fourth method of failure, so there is left only three methods of failure upon which the efficiency of the joint shown in Fig. 19, depends: namely, the first, second and sixth.

The calculation of the value of the various possible methods of failure for a joint such as shown in Fig. 19, would result as follows:

1. Strength of net section of plate between the rivet holes in the outer row = $(P - d)tT$ or $(5 - 7/8)7/16 \times 55{,}000 = 99{,}258.5$ lb.

2. Strength of inner net section and the shearing strength of rivets in the outer row = $(P - 2d)tT + 0.7854d^2S$ or $(5 - 2 \times 7/8)\,7/16 \times 55{,}000 + 0.7854 \times (7/8)^2\,44{,}000 = 104{,}661.12$ lb.

3. Strength of net section of plate between the rivet holes in the inner row added to the crushing strength of the strap in front of the rivets in the outer row = $(P - 2d)tT + t_1dC$ (not effective in obtaining the strength of joint for dimensions shown in Fig. 19).

4. Shearing strength of all the rivets, both in single and double shear = $2 \times 0.7854d^2 2S + 0.7854d^2S$ (not effective for determining the strength of joint for dimensions shows in Fig. 19).

5. Crushing strength of plate in front of the rivets in the inner row, added to the crushing strength of strap in front of the rivets in the outer row = $2tdC + t_1dC$ (not effective in obtaining the strength of joint for dimensions shown in Fig. 19).

6. Crushing strength of the plate in front of inner rivets and shearing strength of the rivets in outer row = $2tdC + 0.7854d^2S$ or $2 \times 7/16 \times 7/8 \times 95{,}000 + 0.7854 \times (7/8)^2\,44{,}000 = 99{,}192.37$ lb. Since the strength of the solid plate is PtT or $5 \times 7/16 \times 55{,}000 = 120{,}312.5$ lb., the efficiency of the joint would be $\frac{99{,}192.37}{120{,}312.5} \times 100$ or 82.4 per cent., for the weakest possible method of failure.

Efficiency of Triple-riveted Butt Joint with Double Straps of Unequal Width.—Estimating the efficiency of this type of joint is practically the same problem as involved in obtaining the strength of the double-riveted joint just considered. Referring to Fig. 20, which illustrates a joint of this type, it will be seen that the only difference between it and the double-riveted joint is that there are two inner rows of rivets in double shear instead of one. As in the case of the double-riveted joint, if t_1 is greater than $0.364d$, the rivets in the outer row will necessarily fail by shearing before causing the crushing of the strap in front of these rivets. If t is less than $0.728d$, the plate in front of the rivets in the inner rows will crush before the rivets will shear. Using the values given in Fig. 20, it will be seen that the $5/8$-in. butt strap is of such thickness that it insures the shearing of the rivets in the outer row, and the $11/16$-in. plate would cause the plate in front of the rivets in the inner rows to crush before these rivets would shear. Therefore the methods of failure involving the crushing of the strap in front of the rivets in the outer row and the shearing of the rivets in the inner rows would not require consideration in obtaining the strength of a joint such as Fig. 20.

The methods of failure to consider in obtaining the efficiency of Fig. 20, would be as follows:

1. Strength of net section of plate between rivets in outer row = $(P - d)tT$ or $(9\frac{1}{2} - 1\frac{1}{16})\,\frac{11}{16} \times 55{,}000 = 319{,}000$ lb.

2. Strength of net section of plate between the rivets in the second row, added to the shearing strength of the rivets in the outer row = $(P - 2d)tT + 0.7854d^2S$ or $(9\frac{1}{2} - 2\frac{1}{8})\frac{11}{16} \times 55{,}000 + 0.7854\,(1\frac{1}{16})^2 44{,}000 = 317{,}882$ lb.

3. Strength of the net section of the plate between the rivets in

the second row, added to the crushing strength of the strap in front of the rivets in the outer row = $(P - 2d)tT + t_1dC$ (not effective in obtaining the efficiency of a joint of these particular dimensions).

4. Shearing of all rivets both in single and double shear = $4 \times 0.7854d^2 2S + 0.7854d^2S$ (not effective in obtaining the efficiency of a joint of these particular dimensions).

5. Crushing of the plate or strap in front of all rivets = $4tdC + t_1dC$ (not effective in obtaining the efficiency of a joint of these particular dimensions).

6. Crushing of the plate in front of the rivets in the inner-rows and the shearing of the rivets in the outer row, in single shear = $4tdC + 0.7854d^2S$ or $4 \times 1\frac{1}{16} \times 1\frac{1}{16} \times 95{,}000 + 0.7854(1\frac{1}{16})^2 44{,}000 =$ 316,593 lb.

Since the strength of the solid plate is PtT, or $9\frac{1}{2} \times 1\frac{1}{16} \times 55{,}000 = 359{,}219$ lb., the efficiency of the joint would be $\frac{316{,}593}{359{,}219} \times 100$, or 88.1 per cent.

Efficiency of Quadruple-riveted Butt Joint with Double Straps of Unequal Width.—With this type of joint, Fig. 21, it would appear, from a cursory examination, to be much more difficult to calculate than the others just considered, but it does not present any greater difficulties than the double- or triple-riveted joints of this form. It will be seen from Fig. 21, that this joint is the same as the triple-riveted joint except that there is an additional row of rivets, in single-shear, the pitch of these rivets being twice as great as those in the second row. While the additional row of rivets would appear to add two more possible modes of failure it does not, as will be seen from the following explanation. The two methods of failure apparently added are the breaking of the net section along the second row of rivets and the shearing of the rivets in the outer row, or the breaking of the net section, along the second row of rivets and the crushing of the strap in front of the rivets in the outer row.

Considering the efficiency of the joint as determined by, first, the breaking of the net section between the rivet holes in the outer row; second, by breaking of the net section between the rivets in the second row and shearing of the rivets in the outer row; third by breaking of the net section between the rivet holes in the third row and shearing of the rivets in the two outer rows, the following would result, in Fig. 21:

1. Efficiency $= \frac{(P - d)tT}{PtT}$

2. Efficiency $= \frac{(P - 2d)tT + 0.7854d^2S}{PtT}$.

3. Efficiency $= \frac{(P - 4d)tT + 3 \times 0.7854d^2S}{PtT}$.

It will be seen by inspection of (1) and (2), that if $dtT = 0.7854d^2S$, or $t = 0.7854d\frac{S}{T}$, then (1) and (2) would become equal to each other; also if this value of t is substituted in equation (3), it will equal (1) and (2). Therefore, for this particular value of t, each of the three methods of failure considered above would give the same joint efficiency. Again, inspecting equations (1), (2) and (3), it is seen that if t is changed in value while the other variables are constant, the change would effect (1) more than (2), and (2) more than (3); therefore the value of (2) is always between the values of (1) and (3), unless it is equal to them. Since the above is true, the value of (2) can never be less than both (1) or (3) in a given joint. Therefore, the value of (2) need never be considered in obtaining the efficiency of a quadruple-riveted joint of this character. Similarly, the three values for the efficiency of the joint as determined by the breaking of the net section and crushing of the strap in front of the rivets, as considered above in the case of the shearing values, would result as follows:

4. Breaking of the outer net section as before; (5) breaking of the second net section and the crushing of the strap in front of the rivets in the outer row; (6) breaking of the net section in the third row and crushing of the strap in front of the rivets in the two outer rows. The efficiency equations for these failures are:

4. Efficiency $= \dfrac{(P - d)tT}{PtT}$

5. Efficiency $= \dfrac{(P - 2d)tT + t_1dC}{PtT}$

6. Efficiency $= \dfrac{(P - 4d)tT + 3t_1dC}{PtT}$

It is seen that when $tdT = t_1dC$, or $t = t_1 \dfrac{C}{T}$, equations (4), (5) and (6), become equal to each other, and any change in the value of t effects (4) more than (5) and (5) more than (6). The value of (5) is therefore always between (4) and (6) unless it is equal to them, which is the case when $t = t_1\dfrac{C}{T}$. It will be seen from the above explanations, that the added row of rivets in the case of the quadruple-riveted joint does not introduce any new method of failure.

Proceeding with the calculation of the efficiency of the joint shown in Fig. 21, using the numerical values as given, it is seen that, t_1, is more than $0.364d$, and t less than $0.728d$; therefore the crushing of the strap in front of the rivets in the outer rows, or shearing of the rivets in double shear in the inner rows, are not factors to be considered in determining the joint efficiency, and the methods of failure which would require consideration to determine the joint efficiency for Fig. 21, would be:

1. Strength of the net section of plate between the rivets in the outer row $= (P - d)tT$ or $(20 - 1\frac{1}{8})\frac{3}{4} \times 55{,}000 = 778{,}594$ lb.

2. Strength of the net section of plate between the rivets in the third row, added to the shearing strength of the three rivets in the outer rows $= (P - 4d)tT + 3 \times 0.7854d^2S$ or $(20 - 4 \times 1\frac{1}{8})\frac{3}{4} \times 55{,}000 + 3 \times 0.7854(1\frac{1}{8})^2 44{,}000 = 770{,}525$ lb.

3. Strength of the net section of plate between the rivets in the third row, added to the crushing strength of the strap in front of the rivets in the outer rows $= (P - 4d)tT + 3t_1dC$ (not effective in a joint of these dimensions).

4. Shearing of all the rivets in single and double shear $= 8 \times 0.7854d^2 2S + 3 \times 0.7854d^2S$ (not effective in a joint of these dimensions).

5. Crushing of plate or strap in front of all rivets $= 8tdC + 3t_1dC$ (not effective in a joint of these dimensions).

6. Crushing strength of the plate in front of the rivets in the inner rows that are in double shear, and shearing of the rivets in the outer rows that are in single shear $= 8tdC + 3 \times 0.7854d^2S$ or $8 \times \frac{3}{4} \times 1\frac{1}{8} \times 95{,}000 + 3 \times 0.7854 \times (1\frac{1}{8})^2 44{,}000 = 772{,}500$ lb.

As the strength of the solid plate is PtT, or $20 \times \frac{3}{4} \times 55{,}000 = 825{,}000$ lb., the efficiency of the joint would be $\dfrac{770{,}525}{825{,}000} \times 100$ or 93.4 per cent.

Efficiency of Quintuple-riveted Butt Joint with Double Straps of Unequal Width.—The quintuple-riveted joint, Fig. 22, appears to be considerably more difficult to calculate than any of those previously considered, but like the quadruple-riveted joint, it does not require any more lengthy calculations than do the double- and the triple-riveted joints of this type.

If the two sets of four equations each, representing the efficiency of this joint due to failure between the rivet holes in the outer row, or failure of the net section between the rivet holes in each of the other three succeeding rows together with the shearing of the rivets, or the crushing of the strap in front of the rivets in the outside rows, are compared; the result will be seen to be as follows: As in the case of the quadruple-riveted joint, for two particular values of t, that is, $0.7854d\dfrac{S}{T}$ for shearing of the rivets, and $t_1\dfrac{C}{T}$, for crushing of the strap, the efficiencies for the different methods of failure for each set would be the same, and for every other value of t the strength of the joint represented by failure through the second or third rows of rivets would be between those values representing failure through the outer net section or through the net section between the rivets in the fourth row to-

gether with the shearing of the rivets in the outside rows, or the crushing of the strap in front of the rivets in the outside rows. From the foregoing it will be seen that only the same number of methods of failure need be considered in estimating the strength of the quintuple-riveted joint as for the others of the type with straps of unequal width.

Proceeding to calculate the efficiency of a quintuple-riveted joint, as in Fig. 22, using the numbered dimensions given, it is first seen that the strap thickness, or t_1, is less than $0.364d$; therefore the failure at the rivets in the outer rows will be by crushing of the strap rather than the rivets shearing; also that the thickness of the plate t is less than $0.728d$, and the failure along the inner rows of rivets which are in double shear will occur by crushing the plate before shearing the rivets. Estimating the value of the various methods of possible failure for the joints in Fig. 22, the following results are obtained: This joint is not a design that should be used, for the rivets are too large for the plate thickness, the design being purposely selected to show crushing of the inner strap by the rivets.

1. Strength of the net section of plate between the rivet holes in the outside row $= (P - d)tT$ or $(24 - 1)\frac{3}{8} \times 55{,}000 = 474{,}375$ lb.

2. Strength of the net section of plate between the rivet holes in the fourth row, added to the shearing strength of the seven rivets in single shear in the outside rows $= (P - 8d)tT + 7 \times 0.7854\, d^2S$ (not effective in obtaining the efficiency of a joint of these dimensions).

3. Strength of the net section of the plate between the rivet holes in the fourth row, added to the crushing strength of the strap in front of the seven rivets in the outer rows $= (P - 8d)tT + 7t_1dC$ or $(24 - 8)\frac{3}{8} \times 55{,}000 + 7 \times \frac{5}{16} \times 1 \times 95{,}000 = 537{,}802$ lb.

4. Shearing of all the rivets in single and double shear $16 \times 0.7854d^2 2S + 7 \times 0.7854d^2S$ (not effective in obtaining the strength of a joint of these dimensions).

5. Crushing strength of the plate or strap in front of all rivets $= 16tdC + 7t_1dC$ or $16 \times \frac{3}{8} \times 1 \times 95{,}000 + 7 \times \frac{5}{16} \times 1 \times 95{,}000 = 777{,}802$ lb.

6. Crushing of the plate in front of the rivets in the inner rows in double shear and shearing of the rivets in the outer rows in single shear $= 16tdC + 7 \times 0.7854d^2S$ (not effective in obtaining the efficiency of a joint of these dimensions).

Since the strength of the solid plate is, PtT or $24 \times \frac{3}{8} \times 55{,}000 = 495{,}000$ lb. the joint efficiency would be $\frac{474{,}375}{495{,}000} \times 100$ or 95.8 per cent.

CHAPTER IV

EFFICIENCIES OF BOILER JOINTS—(Continued)

Efficiency of The Locomotive Joint.—The calculation of the strength of the "locomotive joint," Fig. 24, is practically the same as for the joints previously considered.

Any combination of crushing of the plate or of the strap, or of the shearing of the rivets at the outer row that might act with the double shearing of the rivets in the two inner rows would also act with the single shearing of the rivets in the inner rows; and since the single shear of these rivets would give a much smaller value than when in double shear, the double shear of the rivets in the inner rows need not be considered in calculating the efficiency of this type of joint. Proceeding to calculate the efficiency of Fig. 24, it is first ascertained that the thickness of the strap, t_1 is greater than $0.364d$. Therefore, the crushing of the strap or plate in front of the rivets in any row will not be a factor in determining the strength of this joint, the methods of failure to be considered being as follows:

1. Strength of net section of plate between the rivet holes in the outer row = $(P - d)tT$ or $(5 - \frac{3}{4})\frac{1}{2} \times 55{,}000 = 116{,}875$ lb.
2. Strength of the net section of plate between the rivet holes in the second row added to the shearing strength of the rivets in the outer row = $(P - 2d)tT + 0.7854d^2S$ or $(5 - 2 \times \frac{3}{4})\frac{1}{2} \times 55{,}000 + 0.7854 \times (\frac{3}{4})^2 44{,}000 = 115{,}689$ lb.
3. Strength of net section of plate between the rivets in the second row added to the crushing strength of the strap in front of the rivets in the outer row $(P - 2d)tT + t_1dC$ (not effective in obtaining the efficiency of a joint of these dimensions).
4. Shearing of all the rivets in single shear = $5 \times 0.7854d^2S$ or $5 \times 0.7854 \times (\frac{3}{4})^2 44{,}000 = 97{,}195$ lb.
5. Crushing of the plate or strap in front of all the rivets = $4tdC + t_1dC$ (not effective in obtaining the efficiency of a joint of these dimensions).
6. Shearing of the rivets in the two inner rows in single shear and the crushing of the strap in front of the rivets in the outer row = $4 \times 0.7854d^2S + t_1dC$ (not effective in obtaining the efficiency of a joint of these dimensions).

Since the strength of the solid plate is PtT or $5 \times \frac{1}{2} \times 55{,}000 = 137{,}500$ lb., the joint efficiency would be $\frac{97{,}195}{137{,}500} \times 100$ or 70.7 per cent.

Efficiency of the Sawtooth Joint.—Calculating the efficiency of the sawtooth joint, Fig. 23, is as simple as for the butt-strap joints with straps of equal widths. Examining Fig. 23, it would appear that the methods of failure to be considered would be seven, which are as follows:

1. The breaking of the net section of the plate between the rivet holes in the outer row of rivets = $(P - d)tT$.
2. The shearing of the nine rivets in double shear = $9 \times 0.7854d^2(2S)$.
3. The crushing of the plate in front of the nine rivets = $9Ctd$.[1]
4. Breaking of the net section of the plate along the second row of rivets and shearing of the rivets in the outer row = $(P - 2d)tT + 0.7854d^2(2S)$.

[1] NOTE.—No attention need be paid to the crushing of the straps, since their combined thickness would be more than equal to the plate thickness in commercial boiler joints.

5. Breaking of the net section of the plate along the third row of rivets and the shearing of the rivets in the two outer rows = $(P - 3d)tT + 3 \times 0.7854d^2(2S)$.

6. The breaking of the net section of the plate along the second row of rivets and the crushing of the plate in front of the rivet in the outer row = $(P - 2d)tT + Ctd$.

7. Breaking of the net section of the plate along the third row of rivets, and crushing of the plate in front of the rivets in the two outer rows = $(P - 3d)tT + 3Ctd$.

Dividing the least of these results by the value of PtT will give the efficiency.

While there are seven methods of failure presented, this number may be reduced to two by a preliminary investigation. Examining Fig. 23, and considering methods of failure (4) and (5), it is seen that the net section of the plate at the outer row of rivets is greater in length by one rivet diameter than the net section at the second row, while one rivet in shear is added to the strength of this last section, assuming failure to occur as indicated by (4). For the third row, the length of the net section of the plate is less by two rivet diameters than at the outer row, but three rivets in shear are added to the strength of the joint, assuming failure to occur as indicated by (5). Therefore, it will be seen that until the thickness of the plate is such that the tensile strength of the plate removed by a rivet hole is greater than the shearing strength of a rivet in double shear, failure at the second row of rivets cannot occur. Also, until the thickness of the plate is such that the tensile strength of the plate removed by two rivet holes is greater than the shearing strength of three rivets in double shear, failure at the third row of rivets cannot occur. When the tensile strength of the plate removed by a rivet hole equals the shearing strength of a rivet in double shear, the following equation will apply: $Ttd = 0.7854d^2(2S)$ or $t = 1.2566d$, where $2S$ is 88.000 lb. and T is 55,000 lb. As such thickness with respect to rivet diameter is beyond the range for commercial boiler joints, failure cannot occur as indicated by (4). It is evident that failure will not occur at the third row of rivets as indicated by (5), for the plate thickness required in such event would be one and a half times as great as required for failure by (4). Considering methods of failure (6) and (7) in the same manner as (4) and (5), it is evident that failure cannot occur as given by (6) unless the crushing strength of the plate in front of a rivet is less than the tensile strength of the plate removed by a rivet hole: When these two values equal each other the following equation must be satisfied, $Ctd = Ttd$ or $C = T$. That is, the crushing strength of the plate would necessarily be less than its tensile strength for method of failure (6) to determine the true joint efficiency; therefore, method (6) is not to be considered for commercial boiler joints, for the crushing strength of boiler plate is always in excess of its tensile strength. Considering method of failure (7) in a similar manner; this method could not determine the efficiency of a joint unless the value of C was less than given by $3Ctd = 2Ttd$ or C less than $0.666T$. Therefore, (7) would not be considered in determining the efficiency of a commercial boiler joint. With methods of failure (4), (5), (6) and (7) eliminated, there remains only methods (1), (2) and (3) to be considered. As has been previously shown, where the plate thickness is less than $0.728d$, when C is 95,000 lb. and $2S$ is 88,000 lb. the crushing of the plate will determine the joint efficiency rather than the shearing of the rivets in double shear, and conversely, where the plate thickness is greater than this amount the shearing of the rivets will determine the joint efficiency.

A preliminary determination of the relative value of the plate thickness to rivet diameter will therefore eliminate either method of failure (2) or (3), leaving only two methods to be considered in arriving at the efficiency of a joint as in Fig. 23. Proceeding with the calculation of the efficiency for Fig. 23, it is noted that the ⅞-in. plate thickness, where 1-in. rivet holes are used, is greater than $0.728d$, therefore method of failure (3) would not be considered. In the calculation for efficiency of Fig. 23 the methods of failure to be considered are as follows:

1. The breaking of the net section of the plate between the rivet

holes in the outer row = $(P - d)tT$ or $(12 - 1)\ \frac{7}{8} \times 55{,}000 =$ 529,325 lb.

2. The shearing of nine rivets in double shear = $9 \times 0.7854d^2\ (2S)$ or $9 \times 0.7854 \times (1)^2 \times 88{,}000 = 622{,}037$ lb.

3. The crushing of the plate in front of nine rivets = $9\ Ctd$. (Not effective in obtaining the efficiency of a joint of these dimensions.) Since the strength of the solid plate is PtT, or $12 \times \frac{7}{8} \times 55{,}000 =$ 577,500 lb., the efficiency of a joint, as in Fig. 23, is $\frac{529{,}325}{577{,}500} \times 100 =$ 91.66 per cent.

Ready Reference Equations for Calculating Joint Efficiencies.— The following equations are arranged for ready reference in calculating the efficiencies of riveted joints. In butt joints with straps of unequal width, if the straps are as thick or thicker than the plate, t_1 representing the thickness of the straps must be changed to t representing the thickness of the plate. In butt joints with straps of equal width it is assumed that the thickness of the straps will be at least one-half the plate thickness. Where the thickness of the plate t for lap joints and the thickness of straps t_1 for butt joints with straps of unequal width is greater than $0.7854d\,\frac{S}{C}$[1], equations designated a need not be considered and where t or t_1 is of less value than $0.7854d\,\frac{S}{C}$[1], equations designated b need not be considered in making calculations for efficiencies. In all the types of butt-strapped joints considered, where the thickness of the plate or t is greater than $0.7854d\,\frac{2S}{C}$[1], equations designated c need not be considered, and where t is less than this value, equations e may be omitted from the calculations for efficiencies. Where equations are designated with two letters they may be omitted from the calculations if so indicated by either letter.

[1] Tables I and II at the end of this chapter give the shearing strength of rivets and the plate thickness values for $0.7854d\frac{S}{C}$ and $0.7854d\ \frac{2S}{C}$, for different values of d, S and $2S$.

Single-riveted Lap Joint, Fig. 13.†

$$E = \frac{[P - d]tT}{PtT} \qquad (1)$$

$$E = \frac{0.7854d^2S}{PtT}\ {}_b \qquad (2)$$

$$E = \frac{tdC}{PtT}\ {}_a \qquad (3)$$

Double-riveted Lap Joint, Fig. 14.†

$$E = \frac{[P - d]tT}{PtT} \qquad (1)$$

$$E = \frac{2 \times 0.7854d^2S}{PtT}\ {}_b \qquad (2)$$

$$E = \frac{2tdC}{PtT}\ {}_a \qquad (3)$$

Triple-riveted Lap Joint, Fig. 15.†

$$E = \frac{[P - d]tT}{PtT} \qquad (1)$$

$$E = \frac{3 \times 0.7854d^2S}{PtT}\ {}_b \qquad (2)$$

$$E = \frac{3tdC}{PtT}\ {}_a \qquad (3)$$

Single-riveted Butt Joint with Straps of Equal Width, Fig. 16.†

$$E = \frac{[P - d]tT}{PtT} \qquad (1)$$

$$E = \frac{0.7854d^2 2S}{PtT}\ {}_e \qquad (2)$$

$$E = \frac{tdC}{PtT}\ {}_c \qquad (3)$$

Double-riveted Butt Joint with Straps of Equal Width, Fig. 17.†

$$E = \frac{[P - d]tT}{PtT} \qquad (1)$$

† The true joint efficiency is the least of these values.

$$E = \frac{2 \times 0.7854d^2 2S}{PtT}{}_{c} \quad (2)$$

$$E = \frac{2tdC}{PtT}{}_{c} \quad (3)$$

Triple-riveted Butt Joint with Straps of Equal Width, Fig. 18.†

$$E = \frac{[P - d]tT}{PtT} \quad (1)$$

$$E = \frac{3 \times 0.7854d^2 2S}{PtT}{}_{c} \quad (2)$$

$$E = \frac{3tdC}{PtT}{}_{c} \quad (3)$$

Double-riveted Butt Joint with Straps of Unequal Width, Fig. 19.†

$$E = \frac{[P - d]tT}{PtT} \quad (1)$$

$$E = \frac{[P - 2d]tT + 0.7854d^2S}{PtT}{}_{b} \quad (2)$$

$$E = \frac{[P - 2d]tT + t_1dC}{PtT}{}_{a} \quad (3)$$

$$E = \frac{2 \times 0.7854d^2 2S + 0.7854d^2S}{PtT}{}_{b \text{ or } c} \quad (4)$$

$$E = \frac{2tdC + t_1dC}{PtT}{}_{a \text{ or } c} \quad (5)$$

$$E = \frac{2tdC + 0.7854d^2S}{PtT}{}_{b \text{ or } c} \quad (6)$$

Triple-riveted Butt Joint with Straps of Unequal Width, Fig. 20.†

$$E = \frac{[P - d]tT}{PtT} \quad (1)$$

$$E = \frac{[P - 2d]tT + 0.7854d^2S}{PtT}{}_{b} \quad (2)$$

$$E = \frac{[P - 2d]tT + t_1dC}{PtT}{}_{a} \quad (3)$$

$$E = \frac{4 \times 0.7854d^2 2S + 0.7854d^2S}{PtT}{}_{b \text{ or } c} \quad (4)$$

$$E = \frac{4tdC + t_1dC}{PtT}{}_{a \text{ or } c} \quad (5)$$

$$E = \frac{4tdC + 0.7854d^2S}{PtT}{}_{b \text{ or } c} \quad (6)$$

Quadruple-riveted Butt Joint with Straps of Unequal Width, Fig. 21.†

$$E = \frac{[P - d]tT}{PtT} \quad (1)$$

$$E = \frac{[P - 4d]tT + 3 \times 0.7854d^2S}{PtT}{}_{b} \quad (2)$$

$$E = \frac{[P - 4d]tT + 3t_1dC}{PtT}{}_{a} \quad (3)$$

$$E = \frac{8 \times 0.7854d^2 2S + 3 \times 0.7854d^2S}{PtT}{}_{b \text{ or } c} \quad (4)$$

$$E = \frac{8tdC + 3t_1dC}{PtT}{}_{a \text{ or } c} \quad (5)$$

$$E = \frac{8tdC + 3 \times 0.7854d^2S}{PtT}{}_{b \text{ or } c} \quad (6)$$

Quintuple-riveted Butt Joint with Straps of Unequal Width, Fig. 22.†

$$E = \frac{[P - d]tT}{PtT} \quad (1)$$

$$E = \frac{[P - 8d]tT + 7 \times 0.7854d^2S}{PtT}{}_{b} \quad (2)$$

$$E = \frac{[P - 8d]tT + 7t_1dC}{PtT}{}_{a} \quad (3)$$

$$E = \frac{16 \times 0.7854d^2 2S + 7 \times 0.7854d^2S}{PtT}{}_{b \text{ or } c} \quad (4)$$

† The true joint efficiency is the least of these values.

$$E = \frac{16tdC + 7t_1dC}{PtT}{}_{a \text{ or } c} \tag{5}$$

$$E = \frac{16tdC + 7 \times 0.7854d^2S}{PtT}{}_{b \text{ or } c} \tag{6}$$

Sawtooth Joint, Fig. 23.†

$$E = \frac{[P - d]tT}{PtT} \tag{1}$$

$$E = \frac{9 \times 0.7854d^2 2S}{PtT}{}_{\bullet} \tag{2}$$

$$E = \frac{9tdC}{PtT}{}_{c} \tag{3}$$

TABLE I.—SHEARING STRENGTH OF RIVETS IN SINGLE SHEAR AND VALUES FOR PLATE THICKNESS WHERE SHEARING STRENGTHS AND CRUSHING STRENGTHS ARE EQUAL

Rivet hole, dia. in.	$S = 38,000$ lb.	$0.7854d\frac{S}{C}$	$S = 40,000$ lb.	$0.7854d\frac{S}{C}$	$S = 42,000$ lb.	$0.7854d\frac{S}{C}$	$S = 44,000$ lb.	$0.7854d\frac{S}{C}$
	Shearing strength, lb.	Plate thickness, in.	Shearing strength, lb.	Plate thickness, in.	Shearing strength, lb.	Plate thickness, in.	Shearing strength, lb.	Plate thickness, in.
5/8	11,658	0.196	12,272	0.207	12,885	0.217	13,499	0.227
11/16	14,107	0.216	14,849	0.228	15,591	0.240	16,334	0.250
3/4	16,788	0.236	17,672	0.247	18,555	0.262	19,439	0.273
13/16	19,703	0.255	20,739	0.268	21,776	0.282	22,813	0.296
7/8	22,850	0.275	24,053	0.289	25,255	0.304	26,458	0.318
15/16	26,231	0.295	27,612	0.310	28,992	0.326	30,373	0.341
1	29,845	0.314	31,416	0.331	32,987	0.347	34,558	0.364
1 1/16	33,692	0.334	35,466	0.351	37,239	0.369	39,012	0.386
1 1/8	37,773	0.353	39,761	0.372	41,749	0.391	43,737	0.409
1 3/16	42,086	0.373	44,302	0.393	46,516	0.412	48,732	0.432
1 1/4	46,633	0.393	49,088	0.412	51,542	0.434	53,996	0.455
1 5/16	51,413	0.412	54,119	0.433	56,825	0.456	59,531	0.477
1 3/8	56,426	0.432	56,396	0.453	62,366	0.477	65,335	0.500
1 7/16	61,672	0.452	64,918	0.475	68,164	0.498	71,410	0.523
1 1/2	67,152	0.471	70,686	0.496	74,220	0.521	77,754	0.546

† The true joint efficiency is the least of these values.

TABLE II.—SHEARING STRENGTH OF RIVETS IN DOUBLE SHEAR AND VALUES FOR PLATE THICKNESS WHERE SHEARING STRENGTHS AND CRUSHING STRENGTHS ARE EQUAL

Rivet hole, dia. in.	$2S = 70,000$ lb.	$0.7854d\frac{2S}{C}$	$2S = 76,000$ lb.	$0.7854d\frac{2S}{C}$	$2S = 78,000$ lb.	$0.7854d\frac{2S}{C}$	$2S = 88,000$ lb.	$0.7854d\frac{2S}{C}$
	Shearing strength, lb.	Plate thickness, in.	Shearing strength, lb.	Plate thickness, in.	Shearing strength, lb.	Plate thickness, in.	Shearing strength, lb.	Plate thickness, in.
5/8	21,476	0.362	23,316	0.393	23,930	0.403	26,998	0.455
11/16	25,985	0.398	28,214	0.432	28,956	0.443	32,668	0.500
3/4	30,925	0.434	33,576	0.471	34,460	0.483	38,878	0.546
13/16	36,294	0.470	39,406	0.511	40,442	0.524	45,626	0.591
7/8	42,092	0.505	45,700	0.550	46,904	0.564	52,916	0.637
15/16	48,320	0.542	52,462	0.589	53,842	0.604	60,746	0.682
1	54,978	0.578	59,690	0.628	61,260	0.645	69,116	0.728
1 1/16	62,062	0.615	67,384	0.668	69,158	0.685	78,024	0.773
1 1/8	69,580	0.651	75,546	0.707	77,534	0.725	87,474	0.818
1 3/16	77,525	0.687	84,172	0.746	86,388	0.765	97,464	0.864
1 1/4	85,904	0.723	93,266	0.785	95,720	0.805	107,992	0.909
1 5/16	94,710	0.760	102,826	0.825	105,532	0.846	119,062	0.955
1 3/8	103,943	0.795	112,852	0.864	115,822	0.886	130,670	1.000
1 7/16	113,610	0.832	123,344	0.903	126,590	0.926	142,820	1.046
1 1/2	123,704	0.868	134,304	0.942	137,838	0.967	155,508	1.091

CHAPTER V

BOILER-PLATE MATERIAL

While it is necessary, on account of having definite rules for fixing the maximum allowable working pressure for boilers, to calculate the strength of boiler joints closely, there are some factors that would enter the calculations, if accuracy as to their actual strength was to be obtained, that it is impossible to consider, and which are never considered in estimating the strength of boiler joints. In the manufacture of boiler plate it is customary to roll the plates from an ingot, if the plate is of large size, or cut the plate that has been rolled from an ingot into the sizes required. Owing to the tendency of the elements in the metal, such as sulphur, phosphorus, carbon, etc., to collect in the center and near the top of the ingot while cooling, and as these elements act to harden the steel, the tensile strength is not uniform over the whole plate, but may vary as much as 10,000 lb. per square inch. As the highest tensile strength material is at the center and near the end of the plate, which represents the top of the ingot before being rolled, and as the test strips are usually cut from the edge of the plate, the average tensile strength of a boiler plate is nearly always above the tested tensile strength. Boiler plate is usually required by specification to have a tensile-strength range lying between certain limits, and it is customary to stamp the plate with the minimum strength specified for this range, which means that the actual tensile strength as indicated by the test strips will be greater than the stamped tensile strength. It is customary to use the stamped tensile strength in calculating the safe working pressure for boiler shells. The Boiler Code of the American Society of Mechanical Engineers specifies that the maximum tensile strength as stamped on the plate, and, of course, as used in calculations, shall be 55,000 lb. per square inch.

Boiler plate is not of the same thickness at all points. In rolling plates the rolls bend under the load placed on them and the plate becomes thicker at the center than at the sides, and where the thinnest portion of the plate is used in estimating the safe working pressure for boilers, the actual strength is likely to be considerably more than the calculated strength. It is a fact that the usual form of test specimen does not give the actual tensile strength of the material when in the form of a plate as used in boilers, because in the usual form of test specimen the material has a chance to pull down and reduce in section before the final break occurs, while with a plate of considerable width this opportunity to reduce in section is not nearly as great. The old form of test specimen used by the United States government is illustrated in Fig. 26 and because of the reinforcing effect of the wider section near the net section to be separated, this form of test specimen would show a tensile strength of about 10,000 lb. per square inch, above that which would be indicated by the standard test specimen with the same material, the dimensions for this latter specimen being given in Fig. 27. The actual strength of a plate in a boiler shell would possibly be more closely indicated by the old form of test specimen than the new, but the old form is objectionable for other reasons.

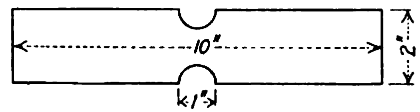


Fig. 26.—Old form of government test specimen.

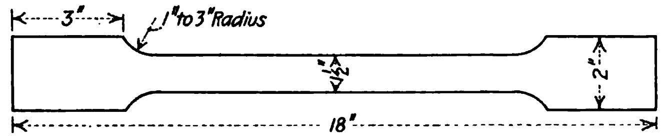


Fig. 27.—Standard form of test specimen.

CHAPTER VI

STRAP THICKNESSES AND RIVET DIAMETERS

In joints where the rivets are spaced wider apart in the outer rows it is evident that the strength of the net section of the straps at the inner rows of rivets would not be equal to the strength of the joint as determined by the failure of the plate or rivets if the combined thickness of the straps just equaled the plate thickness and the tensile strength of the material of both the plate and the straps were the same. Also if in joints using double straps it was required that the combined thickness of the straps just equal the plate thickness, the outer strap, which is the one requiring to be calked, would be too thin to permit a reasonable spacing of the rivets along the calking edge. To provide proper strength for the straps at the inner rows of rivets and to permit a reasonable spacing of the rivets along the calking edge, it is customary to make the thickness of each strap for a double-strapped joint at least 80 per cent. of the plate thickness, that is, the combined thickness of the straps should be not less than 1.6 times the plate thickness. For a discussion of the requirements for strap thickness, see "Thickness of Straps" under "Riveted Joints of Maximum Efficiency," on page 148. In properly designed riveted joints, where the straps are of unequal widths, the rivet-hole diameter should be so chosen with respect to the strap thickness, that failure of the inner strap at the outer row of rivets by crushing would not be possible. Where the strap thickness is to be at least 80 per cent. of the plate thickness and the crushing strength of the plate or strap material is 95,000 lb. per sq. in. and the shearing strength of the rivet material is 44,000 lb. per sq. in., the rivet-hole diameter should be equal to or less than given by the formula: $d = < 2.199t$, to fulfil the above requirements. Table III has been made up showing the different plate thicknesses, the maximum rivet-hole sizes, and the minimum strap

TABLE III.—RELATIONS BETWEEN PLATE THICKNESS, RIVET-HOLE DIAMETER AND STRAP THICKNESS

Plate thicknesses, in.	Minimum strap thickness, in.	Maximum rivet-hole diameter, in.	Plate thicknesses, in.	Minimum strap thickness, in.	Maximum rivet-hole diameter, in.
1/4	1/4	5/8	7/8	23/32	Over 1 1/2
9/32	1/4	5/8	29/32	3/4	.....
5/16	1/4	11/16	15/16	3/4	.....
11/32	9/32	3/4	31/32	25/32	.....
3/8	5/16	13/16	1	13/16	.....
13/32	11/32	7/8	1 1/32	27/32	.....
7/16	11/32	15/16	1 1/16	7/8	.....
15/32	3/8	1	1 3/32	7/8	.....
1/2	13/32	1 1/16	1 1/8	29/32	.....
17/32	7/16	1 1/8	1 5/32	15/16	.....
9/16	7/16	1 3/16	1 3/16	31/32	.....
19/32	15/32	1 1/4	1 7/32	1	.....
5/8	1/2	1 3/8	1 1/4	1	.....
21/32	17/32	1 7/16	1 9/32	1 1/32	.....
11/16	9/16	1 1/2	1 5/16	1 1/16	.....
23/32	19/32	Over 1 1/2	1 11/32	1 3/32	.....
3/4	5/8	.....	1 3/8	1 1/8	.....
25/32	5/8	.....	1 13/32	1 1/8	.....
13/16	21/32	.....	1 7/16	1 5/32	.....
27/32	11/16	.....	1 15/32	1 3/16	.....
			1 1/2	1 7/32	.....

thicknesses that should be used in designing joints of the double butt-strap type. While the same reasoning as to strength does not apply to joints where the straps are of equal widths and the rivet spacing is alike in each row, the same limits should be used in determining the maximum rivet-hole sizes and minimum strap thicknesses used for joints of this type to permit a reasonable spacing of the rivets

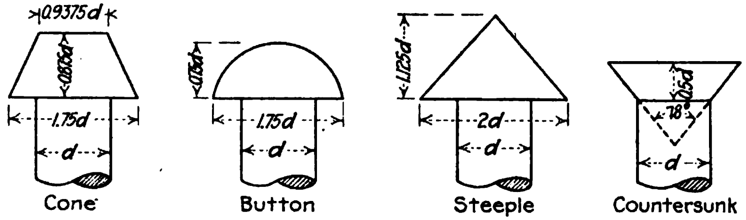


FIG. 28.—Standard shapes for rivet heads.

along the calking edge. It is not desirable in riveted joints for boiler work to have the rivet holes of a diameter less than the plate thickness. The rivet-hole diameter should be allowed to approach the plate thickness only when larger rivets cannot be properly driven. In Table III, the strap thicknesses have been given in the nearest 1/32 in. to the exact size required to make them 80 per cent. of the corresponding plate thickness. When a rivet-hole diameter of 1½ in. has been reached no larger sizes are mentioned as this size is about the limit used in boiler work.

The standard shapes for rivet heads usually employed in boiler work are shown in Fig. 28. The cone and button heads are the ones most commonly used; the steeple head was formerly used more widely than any other, but it has been superseded in recent years by the two former types. The countersunk head is used only in special cases where it is not desired to have the rivet heads project above the surface of the plate.

A rivet head for boiler work should be of sufficient strength to withstand the pull of the shank tending to pull the head off, due to the shrinkage strains set up in cooling after driving; the head should also be of such shape that it may be properly calked, if for any reason it shows a tendency to leak after being driven, and it is on this account that the cone and button shapes have so largely replaced the steeple head. The different dimensions of the heads in Fig. 28, have been given in terms of the shank diameter, and the standard dimensions for the head of a rivet of any size may be readily secured by multiplying the shank diameter by the different factors indicated in the figure for the various dimensions of the head.

CHAPTER VII

LIMITING PITCHES

The question of the limiting pitch of rivets that may be used for a boiler seam and maintain a calkable edge is one that has apparently never been settled. It can never be definitely settled because some of the factors that determine the calkability of a joint cannot be placed on a fixed basis. For example, the fit of the plate along the seam has considerable influence on the question; also the amount of lap allowed beyond the line of rivets along the calking edge. The size of the rivets and heads and even the shape of the heads are important factors.

Factors Determining the Limit to Rivet Pitch.—There are three factors which would seem to govern the maximum pitch of rivets. First, it seems evident that the strength of the plate calculated as a beam with a span equal to the distance between the rivets must be such as to resist the load due to the calking of the edge of the upper plate against the lower without stressing the material beyond its elastic limit. Second, the stiffness of the combination of the upper and lower plate must be such that there will not be enough spring to cause the calking to be effected by the pressure required to make a tight joint. Third, the rivet cross-section should be such that the rivet material will not be stressed beyond its elastic limit, either by maintaining the proper pressure between the calking edge and the underlying sheet, or in holding the upper and lower sheets in contact sufficiently close to permit proper calking.

Strength of Plate in Determining Pitch.—The formula giving the maximum fiber stress for a continuous beam, of rectangular section and uniformly loaded, is: $f = \frac{Wl}{2bd^2}$.

Where f is the maximum fiber stress, W is the total load between supports. l is the distance between supports in inches. b is the breadth and d the depth of the beam in inches.

While nothing may be known about the actual load placed on the sheet by the act of calking, it may be reasonably assumed that there will be required a more or less uniform pressure between the calking edge and the lower plate to insure a tight joint, and this unknown pressure per inch length of seam may be designated by a; the load W in the formula would then become al. It is impossible to assign a definite width for the portion of the calking edge that may be supposed to act as a beam in resisting the pressure between the plates, and furthermore this is not a usual form of continuous beam, for the edge of the sheet is not in line with the rivets. It would seem reasonable to assume that whatever the actual width might be, it would bear some more or less fixed relation to the thickness of the plate; if c represents this ratio, ct may be substituted for the value of b. By substituting t for d, so that the plate thickness will be represented by the usual letter, and substituting P for l, for the same reason with respect to the pitch of rivets, the formula becomes $f = \frac{aP^2}{2ct^3}$. It will be recognized at once that the rivet heads, which are the supports for the continuous beam that the calking edge of the plate is supposed to represent, are so large with respect to the total distance between supports that the length l should be given a less value than P, and it would seem reasonable to assume l as $P - d$, where d is the diameter of the rivet hole, the above formula becoming under these conditions

$$f = \frac{a(P - d)^2}{2ct^3} \tag{1}$$

It will be seen from formula (1) that the strength of the plate between rivets varies as the square of the pitch less the diameter of the rivet holes, and inversely as the cube of the plate thickness.

Assuming formula (1) to truly represent the relation that must exist between the different factors considered, to maintain calkability, if a combination of values are assigned to P and t, so that the sheet would be stressed to the allowable maximum value for f, it would then be possible by means of formula (1) to tell what other combinations of these joint dimensions would give the same value for f. It is true that with a butt-strap joint having 5/16-in. straps and 13/16-in. rivet holes, the rivets can be spaced 3 in. apart and permit proper calking. This is almost the limit for the spacing of rivets under these conditions that will permit proper calking with average construction; therefore in formula (1), by substituting C for the constant but unknown value of $\frac{a}{2c}$, and a value of 3 for p, 5/16 for t, and 13/16 for d, the result would be

$$\frac{f}{C} = \frac{(P - d)^2}{t^3} = \frac{(2.1875)^2}{(0.3125)^3}$$

or $P = \sqrt{156.8t^3} + d$. Assuming t to have values of 5/16, 1/2, 3/4, 1 and 1 1/4, the corresponding values of P would be $2.18 + d$, $4.427 + d$, $8.133 + d$, $12.52 + d$, and $17.50 + d$. The inference to be drawn from the above figures is that the strength of the plate between the rivets is not a factor in determining the limit for pitch, because when the material in a thick plate is stressed to an amount equal to that in a thin plate with a calkable edge, the resulting pitches for the thick plates are much too great to permit of calking.

Deflection of Plate in Limiting Pitch.—The deflection of a uniformly loaded beam of rectangular section is,

$$\text{Deflection} = \frac{Wl^3}{32Ebd^3} \tag{2}$$

in which W, l, b and d have the same significance as given in the formula for the maximum strength of a similar beam, and E represents the modulus of elasticity of the material. Making a and c represent the assumed constant pressure per inch of length along the calking edge, and the ratio between the thickness of plate and the width of the portion of the plate that is assumed to act as a beam along the calking edge, and substituting P for l as was previously done; and representing the deflection by D, formula (2) becomes

$$\frac{32DEc}{a} = \frac{P^4}{t^4} \tag{3}$$

Taking the actual value of l in formula (2) as $P - d$, and not the pitch direct, and using B to represent the constant value $\frac{32Ec}{a}$, formula (3) becomes

$$DB = \frac{(P - d)^4}{t^4} \tag{4}$$

If as before it is assumed, that 3 for P, 5/16 for t, and 13/16 for d, represent a combination of joint dimensions that give the greatest value for D that can be used and present a calking edge sufficiently stiff to permit proper calking, P from formula (4) then becomes

$$P = 7t + d \tag{5}$$

Comparing the variations in P for different plate thicknesses that would give the same deflection by means of formula (5) the results would be as follows: The permissible spacing of rivets for 5/16-, 1/2-, 3/4-, 1- and 1 1/4-in. plate would be $2.185 + d$, $3.5 + d$, $5.25 + d$, $7.0 + d$, and $8.75 + d$. It will be noted that for the thinner plates this range of values for pitch appear to agree in a measure with the limiting values determined by practice, and the stiffness of the plate may be assumed to be a controlling factor in determining the maximum pitch of rivets for thin plates, where rivets of considerable size are used.

Strength of Rivets in Limiting Pitch.—The attempt to obtain the proper relation between the size of rivet, plate thickness, and pitch

limit is not at all satisfactory, and experience is possibly the only guide that can be used to determine these relations. If the pressure along the calking edge was the only factor to be considered the problem would be simple. The pressure along the calking edge is, however, not the only load imposed on the rivets because they are required to hold the sheets together in more or less intimate contact all the way across the seam in addition to withstanding the shearing stress brought upon them in resisting the tendency of the pressure to rupture the shell. The tension on the rivets required to hold the sheets together is an unknown quantity, as it must vary considerably with the condition of the sheets along the joint, that is, depending upon whether the shell sheets fit together properly or tend to spring apart. This stress on the rivets due to holding the sheets together will also be greater for thick than for thin sheets. As the deflection of a beam varies inversely as the cube of its depth, it is likely that the stress on the rivets due to holding the plates together varies as the cube of the plate thickness. A formula that appears to well fit experience over the range of rivet sizes considered here, *i.e.*, ⅝ to 1½ in. in diameter, is

$$P = 5d^2 - 1.5t^3 \qquad (6$$

and the limiting pitches given in the following tables and used in the joint diagrams are based on formulas (5) and (6).

Limiting Pitches for Lap Joints.—Formula (5) was developed from the consideration of such dimensions as have been found practical for butt, double-strap joints. With lap joints where the effect of the straps is not present to aid in producing stiffness for the underlying plate, it is found necessary to shorten the pitch to secure sufficient stiffness along the calking edge. Experience shows that the limiting pitches that may be used for butt-strap joints must be reduced by about 25 per cent. to make them applicable to lap joints, and formula (5) would become $P = 4.7t + d$ for such joints. Of course formula (6) should govern for lap joints the same as for butt joints, and no change would be made in the pitch for either type where the strength of rivets was the governing factor. Those who may be interested in checking up the figures given in the tables for limiting pitches will find that the values do not check accurately with the formulas at every point. This is because the values for maximum pitch were plotted, and where the values given by the two formulas intersected an arc of a circle was drawn to make a smooth connection for the lines instead of having them meet at an angle. In checking over the values giving the limiting pitches for butt joints it should be remembered that the calking edge is that of the strap and not of the plate, and that the strap thickness is assumed to be 80 per cent. of the plate thickness. For convenience the tables are arranged to apply to the plate thickness rather than to strap thickness. It is desired that the reader should thoroughly understand that no claim is made that formulas (5) and (6) have any particular significance in determining the limiting pitches that may be applied to riveted joints, but they were used because they appeared to be corroborated by experience for the usual plate thicknesses and rivet diameters used in boiler construction.

Rivet holes larger than 1¼ in. in diameter are rarely used in stationary-boiler construction, and therefore experience as to the limits for pitch of rivets of large size is not commonly acquired, and it may be that the tabular values given for rivets beyond this size may not be as reliable as for the sizes more commonly used.

Limiting Pitches for Single-riveted Lap Joints.—While the tabular values for the limiting pitches for lap joints may be applied to single-riveted joints over most of the range covered, it should be noted that the single-riveted joint is not so stiff a structure as a joint containing more rivets across the seam, and the tabular values are no doubt somewhat high for this type of joint. However, it was not thought advisable to prepare a special table for the single-riveted joint. Another point in connection with the use of the tabular values for single-riveted joints should be noted, and that is that when such joints are used for the purpose of joining the courses of a horizontal return-tubular boiler at the girth seams, the tubular values should not be used, because in such seams severe stresses are set up by the expansion and contraction of the sheets due to temperature changes. The rivets are required to be spaced es-

pecially close to maintain a tight joint, both by stiffening the seam, and also by the protection from the heat of the furnace afforded by the rivet heads to a large percentage of the surface of the outer lapping plate.

The values for limiting pitch in the following tables, for convenience are given in terms of the outside pitch, and for this reason there are two tables for butt-strap joints with straps of unequal width, one for double- and triple-riveted joints of this kind, where the calking pitch is one-half of the outer pitch, and one for quadruple riveting, where the calking pitch is one-fourth of the outer pitch. The minimum pitches are based on the closest spacing of the rivets in the widest pitch that will permit of the convenient driving of the rivets along the calking edge without special arrangement of the dies, the space figured between rivet heads being approximately 1/2 in.

TABLE IV.—LIMITING PITCHES FOR LAP JOINTS AND JOINTS WITH SINGLE STRAPS

(Straps are assumed to be at least equal to the plate thickness)

Diameter of Rivet Holes, In.

Plate thickness, in.	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 3/16	1 1/4	1 5/16	1 3/8	1 7/16	1 1/2
	Minimum pitches, in.														
	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/16	2 1/4	2 3/8	2 1/2	2 9/16	2 11/16	2 13/16	2 15/16	3	3 1/8
	Maximum pitches, in.														
1/4	1 13/16	1 13/16													
5/16	1 13/16	2	2 1/4	2 1/4											
3/8	1 7/8	2 1/8	2 7/16	2 1/2	2 5/8	2 11/16	2 3/4								
7/16	1 13/16	2 3/16	2 1/2	2 13/16	2 7/8	3	3 1/16	3 1/8	3 3/16	3 1/4	3 5/16	3 3/8	3 7/16		
1/2	1 3/4	2 1/8	2 9/16	2 7/8	3 1/8	3 1/4	3 3/8	3 5/8	3 7/16	3 1/2	3 9/16	3 11/16	3 11/16	3 3/4	3 13/16
9/16	....	2 1/16	2 9/16	2 15/16	3 1/4	3 1/2	3 5/8	3 11/16	3 3/4	3 13/16	3 7/8	3 15/16	4	4	4 1/8
5/8	....	....	2 7/16	2 15/16	3 5/16	3 5/8	3 7/8	4	4 1/16	4 1/8	4 3/16	4 1/4	4 1/4	4 5/16	4 7/16
11/16	....	....	....	2 13/16	3 1/4	3 5/8	4	4 5/16	4 3/8	4 3/8	4 7/16	4 1/2	4 9/16	4 5/8	4 11/16
3/4	....	....	....	....	3 3/16	3 5/8	4	4 7/16	4 9/16	4 11/16	4 3/4	4 13/16	4 7/8	4 7/8	5
13/16	....	....	....	....	....	3 9/16	4	4 1/2	4 11/16	5	5 1/16	5 1/8	5 1/8	5 3/16	5 5/16
7/8	....	....	....	....	....	....	3 15/16	4 7/16	4 3/4	5 3/16	5 5/16	5 5/8	5 7/16	5 1/2	5 5/8
15/16	....	....	....	....	....	....	....	4 3/8	4 3/4	5 1/4	5 1/2	5 11/16	5 3/4	5 13/16	5 7/8
1	....	....	....	....	....	....	....	....	4 5/8	5 1/4	5 9/16	5 7/8	6 1/16	6 1/8	6 3/16
1 1/16	....	....	....	....	....	....	....	....	....	5 3/16	5 9/16	5 15/16	6 3/16	6 3/8	6 1/2
1 1/8	....	....	....	....	....	....	....	....	....	....	5 7/16	5 15/16	6 3/16	6 9/16	6 13/16
1 3/16	....	....	....	....	....	....	....	....	....	....	....	5 7/8	6 3/16	6 3/8	7
1 1/4	....	....	....	....	....	....	....	....	....	....	....	....	6 1/16	6 9/16	7 1/16
1 5/16	....	....	....	....	....	....	....	....	....	....	....	....	....	6 1/8	7
1 3/8	....	....	....	....	....	....	....	....	....	....	....	....	....	....	6 15/16

TABLE V.—LIMITING PITCHES FOR BUTT JOINTS WITH DOUBLE STRAPS OF EQUAL WIDTH

(Strap thickness assumed to be 80 per cent. of plate thickness)

Diameter of Rivet Holes, In.

Plate thickness, in.	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 3/16	1 1/4	1 5/16	1 3/8	1 7/16	1 1/2
	Diameter pitches, in.														
	1 1/2	1 5/8	1 3/4	1 7/8	2	2 1/16	2 1/4	2 3/8	2 1/2	2 9/16	2 11/16	2 13/16	2 15/16	3	3 1/8
	Maximum pitches, in.														
1/4	1 15/16														
5/16	1 15/16	2 5/16													
3/8	1 15/16	2 5/16	2 3/4	2 13/16											
7/16	1 7/8	2 5/16	2 3/4	3 1/16	3 1/4	3 5/16									
1/2	1 7/8	2 1/4	2 11/16	3 3/16	3 7/8	3 11/16	3 3/4	3 13/16							
9/16	....	2 3/16	2 11/16	3 3/16	3 11/16	3 7/8	4 3/16	4 3/16	4 3/16	4 5/16					
5/8	....	....	2 5/8	3 1/8	3 5/8	4	4 3/8	4 9/16	4 5/8	4 11/16	4 3/4	4 13/16	4 7/8		
11/16	....	....	....	3 1/16	3 9/16	4 1/16	4 1/2	4 7/8	5	5 1/16	5 1/16	5 1/8	5 1/4	5 5/16	5 3/8
3/4	....	....	....	....	3 1/2	4 1/16	4 9/16	5	5 1/4	5 7/16	5 7/16	5 1/2	5 9/16	5 5/8	5 3/4
13/16	....	....	....	....	....	3 15/16	4 1/2	5 1/16	5 7/16	5 5/8	5 3/4	5 13/16	5 15/16	6	6 1/16
7/8	....	....	....	....	....	....	4 7/16	5 1/16	5 1/2	5 3/4	6 1/16	6 3/16	6 1/4	6 5/16	6 7/16
15/16	....	....	....	....	....	....	....	5	5 1/2	5 7/8	6 3/16	6 1/2	6 5/8	6 11/16	6 3/4
1	....	....	....	....	....	....	....	....	5 7/16	5 7/8	6 5/16	6 5/8	6 15/16	7 1/16	7 1/8
1 1/16	....	....	....	....	....	....	....	....	....	5 7/8	6 5/16	6 3/4	7 1/8	7 3/8	7 7/16
1 1/8	....	....	....	....	....	....	....	....	....	....	6 5/16	6 13/16	7 1/4	7 9/16	7 15/16
1 3/16	....	....	....	....	....	....	....	....	....	....	....	6 13/16	7 1/4	7 11/16	8
1 1/4	....	....	....	....	....	....	....	....	....	....	....	....	7 1/4	7 3/4	8 1/8
1 5/16	....	....	....	....	....	....	....	....	....	....	....	....	....	7 3/4	8 3/16
1 3/8	....	....	....	....	....	....	....	....	....	....	....	....	....	....	8 1/4

Table VI.—Limiting Pitches for Butt and Double-strap Joints

(Straps of unequal width, double- and triple-riveting, strap thickness assumed 80 per cent of plate thickness)

Diameter of Rivet Holes, In.

Plate thickness, in.	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 3/16	1 1/4	1 5/16	1 3/8	1 7/16	1 1/2
	Minimum pitches, in.														
	3 1/16	3 1/4	3 1/2	3 3/4	3 15/16	4 1/8	4 1/2	4 3/4	4 15/16	5 1/8	5 7/16	5 9/16	5 13/16	6	6 1/4
	Maximum pitches, in.														
1/4	3 7/8														
5/16	3 7/8	4 5/8													
3/8	3 7/8	4 5/8	5 1/2	5 5/8											
7/16	3 3/4	4 5/8	5 1/2	6 1/8	6 1/2	6 5/8									
1/2	3 3/4	4 1/2	5 3/8	6 3/8	6 7/8	7 3/8	7 1/2	7 5/8							
9/16	.....	4 3/8	5 3/8	6 3/8	7 1/8	7 3/4	8 3/8	8 3/8	8 3/8	8 5/8					
5/8	.....	.....	5 1/4	6 1/4	7 1/4	8	8 3/4	9 1/8	9 1/4	9 3/8	9 1/2	9 5/8	9 3/4		
11/16	.....	.....	.....	6 1/8	7 1/8	8 1/8	9	9 3/4	10	10 1/8	10 1/8	10 1/4	10 1/2	10 5/8	10 3/4
3/4	.....	.....	.....	.....	7	8 1/8	9 1/8	10	10 1/2	10 7/8	10 7/8	11	11 1/8	11 1/4	11 1/2
13/16	.....	.....	.....	.....	.....	7 7/8	9	10 1/8	10 7/8	11 1/4	11 1/2	11 5/8	11 7/8	12	12 1/8
7/8	.....	.....	.....	.....	.....	.....	8 7/8	10 1/8	11	11 1/2	12 1/8	12 3/8	12 1/2	12 5/8	12 7/8
15/16	.....	.....	.....	.....	.....	.....	.....	10	11	11 3/4	12 3/8	13	13 1/4	13 3/8	13 1/2
1	.....	.....	.....	.....	.....	.....	.....	.....	10 7/8	11 3/4	12 5/8	13 1/4	13 7/8	14 1/8	14 1/4
1 1/16	.....	.....	.....	.....	.....	.....	.....	.....	.....	11 3/4	12 5/8	13 1/2	14 1/4	14 3/4	14 7/8
1 1/8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	12 5/8	13 5/8	14 1/2	15 1/8	15 5/8
1 3/16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	13 5/8	14 1/2	15 3/8	16
1 1/4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14 1/2	15 1/2	16 1/4
1 5/16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	15 1/2	16 3/8
1 3/8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	16 1/2

Table VII.—Limiting Pitches for Butt and Double-strap Joints

(Straps of unequal width, quadruple-riveting, strap thickness assumed 80 per cent. plate thickness)

Diameter of Rivet Holes, In.

Plate thickness, in.	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 3/16	1 1/4	1 5/16	1 3/8	1 7/16	1 1/2
	Minimum pitches, in.														
	6 1/8	6 9/16	7	7 1/2	7 7/8	8 5/16	9	9 7/16	9 7/8	10 5/8	16 3/4	11 1/8	11 5/8	12	12 1/2
	Maximum pitches, in.														
1/4	7 3/4														
5/16	7 3/4	9 1/4													
3/8	7 3/4	9 1/4	11	11 1/4											
7/16	7 1/2	9 1/4	11	12 1/4	13	13 1/4									
1/2	7 1/2	9	10 3/4	12 3/4	13 3/4	14 3/4	15	15 1/4							
9/16	.....	8 3/4	10 3/4	12 3/4	14 1/4	15 1/2	16 3/4	16 3/4	16 3/4	17 1/4					
5/8	.....	.....	10 1/2	12 1/2	14 1/2	16	17 1/2	18 1/4	18 1/2	18 3/4	19	19 1/4	19 1/2		
11/16	.....	.....	.....	12 1/4	14 1/4	16 1/4	18	19 1/2	20	20 1/4	20 1/4	20 1/2	21	21 1/4	21 1/2
3/4	.....	.....	.....	.....	14	16 1/4	18 1/4	20	21	21 3/4	21 3/4	22	22 1/4	22 1/2	23
13/16	.....	.....	.....	.....	.....	15 3/4	18	20 1/4	21 3/4	22 1/2	23	23 1/4	23 3/4	24	24 1/4
7/8	.....	.....	.....	.....	.....	.....	17 3/4	20 1/4	22	23	24 1/4	24 3/4	25	25 1/4	25 3/4
15/16	.....	.....	.....	.....	.....	.....	.....	20	22	23 1/2	24 3/4	26	26 1/2	26 3/4	27
1	.....	.....	.....	.....	.....	.....	.....	.....	21 3/4	23 1/2	25 1/4	26 1/2	27 3/4	28 1/4	28 1/2
1 1/16	.....	.....	.....	.....	.....	.....	.....	.....	.....	23 1/2	25 1/4	27	28 1/2	29 1/2	29 3/4
1 1/8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	25 1/4	27 1/4	29	30 1/4	31 1/4
1 3/16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	27 1/4	29	30 3/4	32
1 1/4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	29	31	32 1/2
1 5/16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	31	32 3/4
1 3/8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	33

CHAPTER VIII

BOILER-JOINT DIAGRAMS

Plates 1 to 76 shown on pages 39 to 113 are original and represent a new treatment of the subject of calculating the strength of riveted seams. An explanation of the use of these diagrams is hardly necessary for their application is almost self-evident. They may be used to find the efficiency of a joint already constructed, as is required of the boiler inspector in fixing the maximum allowable working pressure, or they may be used for the purpose of designing joints. They tell at a glance and without calculation what the best possible arrangement for joint strength is, and there is left no doubt in the designer's mind as to whether there is a possibility of a better arrangement being selected or not. All of the diagrams given are based on a tensile strength of 55,000 lb. per square inch and a crushing strength of 95,000 lb. per square inch for plate material, and 44,000 and 88,000 lb. per square inch for the shearing strength of rivet material when subjected to single and to double shear respectively. In Chapter X are given complete instructions for making such diagrams, so that they may be readily reproduced for other values of plate and rivet strength if desired.

Determining Joint Efficiency by Use of Diagrams.—A rule for finding the joint efficiency by means of any of these diagrams may be stated as follows:

Rule.—Select the diagram for the type of joint and the rivet-hole size required, follow down the vertical line representing the given pitch of rivets until it intersects a line representing the given plate thickness, the horizontal line passing through or near this intersection will indicate the required joint efficiency. If the vertical line representing the given pitch does not intersect a line marked for a plate thickness as small as the plate under consideration then the intersection of the pitch line with the top line sloping down to the left, or the last line sloping down to the right as the case may be, will indicate the joint efficiency.

Diagrams for Lap-riveted and Butt-strap Joints, with Straps of Equal Width.—There is but one set of diagrams for joints of these types, this set being for single- and double-riveting. The same diagram is used for both lap and butt-strap joints where the same kind of riveting is used, the only difference being in the plate thickness represented by the lines on the diagram. For example, the diagram for 7/8-in. rivet holes on page 43 gives the efficiency of single- and double-riveted lap joints with straps of equal width, the words single-riveted and double-riveted along the top line indicating the portion of the diagram for each kind of riveting. The figures along the top line of the diagram sloping down to the left represent plate thicknesses, as do similar figures along the bottom and the sides. The upper figures, and those placed to the left where they are arranged in a horizontal manner (these figures represent the lower value of the two) represent the plate thicknesses for lap joints, and the others, which, it will be noted, are twice the value of the first, are for butt-strap joints.

The pitch of rivets is represented by vertical lines the values of which are given across the top of the diagram, while the horizontal lines represent joint efficiency and their values in 5 per cent. increments are placed at each side of the diagram. The diagonal lines sloping down to the right represent the plate thickness noted at each end of these lines, the last one to the right marked with the thinnest plate dimension (this line being dotted in the case of the single-riveted

joints to serve as a dividing line between the portions of the diagram representing single- and double-riveting) representing in addition to the plate dimension marked on it, any plate thinner than this indicated dimension. The top line of the diagram sloping up to the right represents at any given point all plate thicknesses of less value than the one noted immediately to the left of the point considered. For example, using the diagram for ⅞-in. rivet holes on page, 43, the dotted line representing the minimum plate thickness for the single-riveted lap joint is labelled 0.318 in., and if it was desired to find the efficiency of a single-riveted lap joint in a 5⁄16-in. plate, which is slightly less than 0.318 in., the pitch of rivets being 2½ in., the vertical line representing this pitch should be followed down until it intersected the dotted line, the intersection falling at a point denoting a joint efficiency of about 60.5 per cent. The 2½-in. pitch line intersected the top line of the diagram, but beyond a point where it represented a single-riveted joint, and therefore this intersection is not to be considered in finding the efficiency of a single-riveted joint. With 11⁄32-in. plate, 2¼-in. pitch and ⅞-in. diameter rivet holes, the joint efficiency would be 61 per cent., denoted by the intersection of the top line with the pitch line representing 2¼ in. because 11⁄32-in. plate is thinner than any plate represented by a line sloping down to the right which intersects the 2¼-in. pitch line, which is the one being considered; therefore, the intersection between this pitch line and the top line of the diagram is the one determining the joint efficiency. If the pitch with the 11⁄32-in. plate had been 2½ in. instead of 2¼ in., the joint efficiency would have been 56 per cent., which is the efficiency denoted by the intersection of the 2½-in. pitch line with the diagonal line, representing 11⁄32 in. plate thickness, for single-riveted lap joints.

Double-riveted Butt Joints with Straps of Equal Width.—To further illustrate the use of the diagrams in obtaining the efficiency of joints, assume that it is desired to ascertain the efficiency of a butt-strap joint of the following dimensions: ⅞-in. rivet holes pitched 3 in. apart in plate 11⁄16 in. thick. Starting at the 3-in. pitch line, it is seen that it does not intersect a line for double riveting marked to represent a plate thickness as small as 11⁄16 in. for butt-strap joints (the lower figures); therefore, the intersection of the 3-in. pitch line with the top line of the diagram gives the required joint efficiency, which is nearly 71 per cent. If the pitch had been 4 in. instead of 3 in., the joint efficiency would have been 70 per cent., as denoted by the intersection of the 4-in. pitch line with the line representing 11⁄16 in. plate for double-riveted butt-strap joints.

Butt-strap Joints with Straps of Unequal Width.—The diagrams for this type of joint are all of the same form, and an explanation of the use of a diagram for one kind of riveting will serve for all.

Take the diagram for 15⁄16-in. rivet holes and quadruple-riveting, as given on page 89, and assume that it is desired to know the efficiency of this joint with rivet holes spaced 15 in. apart along the outer row, and where a plate thickness of 9⁄16 in. is used. Following down the 15-in. pitch line, it does not intersect a line representing a plate as thin as 9⁄16 in.; therefore, the intersection of the 15-in. pitch line with the top line of the diagram gives the joint efficiency, which is nearly 94 per cent., say 93.75 per cent. The maximum thickness denoted by the top line is given in decimals at the extreme left end of this line, or 0.589 in. in the case of 15⁄16-in. rivet holes. If the plate thickness had been 11⁄16 in. with the same dimensions for rivet-hole diameter and pitch, the efficiency would have been slightly over 91 per cent., as denoted by the intersection of the 15-in. pitch line with the line representing 11⁄16-in. plate.

There is one point about the diagrams for butt joints with straps of unequal width that should be explained, and this is with respect to such joints as might be constructed with very thin straps. The straps to be used with any given size of rivet hole should not be less

than the dimensions marked for the last line sloping down to the right of the diagram for the particular rivet-hole size under consideration, in order that the true joint efficiency may be shown by the diagram, unless for thinner straps the plate thickness and strap thickness are equal or the plate thickness is less than the strap thickness.

It will, of course, be understood that the joint diagrams for butt joints with straps of equal width would not give the true joint efficiency if the straps were of less than half the plate thickness, unless the combined thickness of the straps was used in place of the plate thickness. The above limitations to the diagrams are negligible as the limits are considerably beyond the range for the relation between plate thickness and rivet diameter in commercial boiler joints. Since the strap thickness in such joints is always arranged to be equal to or in excess of 80 per cent. of the plate thickness, it is only necessary to use plates in excess of a fixed minimum thickness for each rivet-hole size to insure that the diagrams will be applicable. In giving the plate thicknesses on the maximum pitch lines used on the diagrams, the lowest value for plate thickness specified is one that may be used and have the diagrams indicate the true joint efficiency. For example, if with $^{15}\!/_{16}$-in. diameter rivet holes, a plate not less than $^{7}\!/_{16}$ in. in thickness is used, the diagram will show the true efficiency, and if plate thinner than this is used, the straps should be at least 0.341 in. thick, unless the plate thickness and strap thickness are to be equal to each other. The reasons why the diagrams cannot show the joint efficiency except within the above limits is explained in the next chapter.

Methods of Joint Failure.—While these diagrams show the efficiency of a joint direct and there is no need to know the method of joint failure that governs the efficiency, the diagrams do show the method of failure that the calculations for strength would indicate to be the weakest. It will be noted that a small skeleton diagram is shown on each of the diagrams for joints with straps of unequal width. The different methods of joint failure are indicated on these skeleton diagrams. Where the intersection between pitch lines and plate-thickness lines fall in the areas of the main diagram corresponding to those in the skeleton diagram, the method of joint failure determining the efficiency will be as indicated on the skeleton diagram. The breaking of the net section of the plate between the rivet holes of the outer row is indicated by intersections along the top line of the diagrams. The crushing of the plate in front of all rivets is indicated by intersections along the line sloping down to the right and denoting the minimum plate thickness. No skeleton diagram is placed on the diagrams for lap joints and butt joints with straps of equal width because there is only one area inclosed by the bounding lines, and all intersections falling in this area denote that the rivets shear, while intersections on the top line or the one to the extreme right, denote failure of the outer net section, or crushing of plate in front of the rivets. This indication of the method of joint failure determining the efficiency makes it easy to calculate a joint efficiency closer than can be read on the diagrams, if such accuracy in figuring is desired; for only the one method of failure together with the strength of the solid plate need be determined to arrive at the fraction indicating the efficiency. It will, however, be found that there is no need for making such calculations, as the diagrams can be read sufficiently close for all practical purposes, and more closely than such calculations are usually made.

Use of the Diagrams for Designing Joints.—The use of these diagrams for the purpose of designing joints is the same as shown above, that is, the maximum practicable joint efficiency can be determined directly from the diagrams, and the designer need pay attention only to the practical limits to pitch for calking, or to rivet size as may be determined by the driving capacity of the riveting equipment. Because the range of rivet-hole diameters to plate thicknesses in these diagrams is so wide, the designer can arrive at once at the best combination for strength, where the limit to rivet size that may be driven has been reached, and plate thicknesses beyond those that would ordinarily be considered must be used in connection with these limiting rivet sizes, to secure a shell of sufficient strength for the purpose

desired. This problem is continually arising in the boiler shop which attempts to build special vessels and much material is wasted because the best spacing of rivets is not adopted.

Maximum Pitch Lines.—On all butt joints where the straps are of unequal width and for the sawtooth type of joint, a line representing the maximum pitch values for calking has been drawn, the values for these maximum pitches having been obtained as explained under limiting pitches, page 29, to aid the designer. Where the plate thickness is such that a pitch line that would represent the maximum to be used for calking does not intersect a line marked for that plate thickness, the maximum pitch line is carried above the diagram and points marked on it at such positions as to indicate the maximum pitch for each plate thickness, each particular plate thickness being indicated by a point. The shape of this curve above the diagram is without meaning; a straight line would have answered the purpose equally well. Minimum pitch lines are placed on the diagrams where the closest practical pitch falls within the range of the pitches given on the diagrams and where the minimum pitch is beyond the range of the diagrams the minimum pitch value is given on the diagram. Maximum pitch lines have not been placed on the diagrams for lap and butt-strap joints with straps of equal width, as there would be two such lines for each diagram to cover both lap joints and those with butt straps.

As an example of the use of the maximum pitch lines in designing joints, assume that it is desired to know the maximum practical efficiency for a joint of the quadruple-riveted type with straps of unequal widths, and using 1-in. rivet holes. By consulting the diagram for this joint with 1-in. diameter holes, on page 90, it is seen that the maximum pitch line crosses the top line of the diagram at about a 17½-in. pitch, and that this top line represents as a maximum a plate of slightly more than ⅝ in. at this point; therefore, 1-in. rivet holes used in a ⅝-in. plate and spaced 17½ in. apart in the outer row, with quadruple-riveting, would give a joint efficiency of 94.3 per cent., which would be about the highest practical efficiency possible with this combination. It is also seen from the diagram that the efficiency would be only slightly improved by exceeding the maximum pitch distance, and would decrease rapidly for this size plate after 17¾ in. was exceeded.

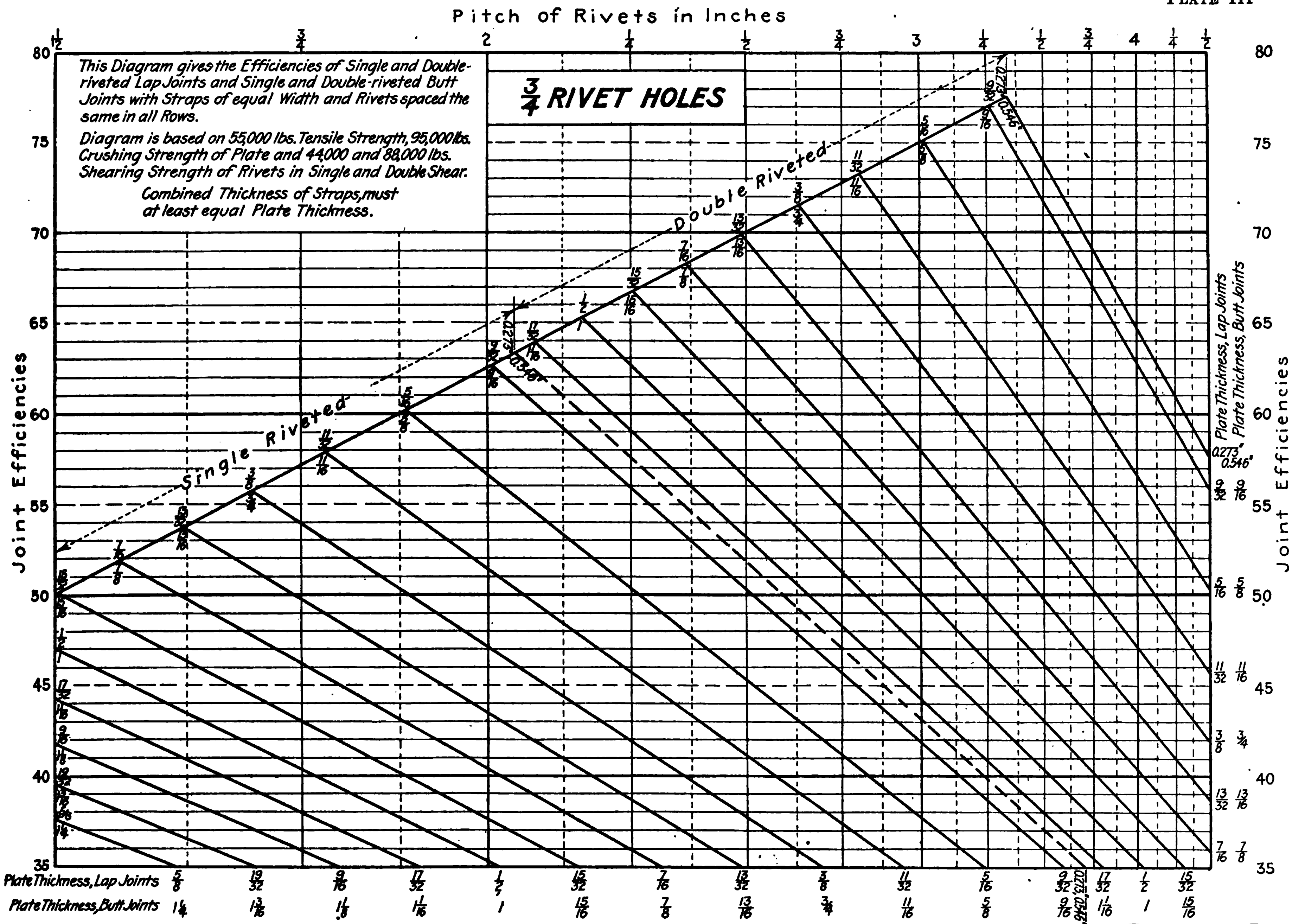
Sawtooth Joint.—The diagrams for the sawtooth type of joint are used in the same manner as those for the lap joints or for the butt-strap joints with straps of equal width. However, it will be noted that the diagrams for this joint are provided with maximum pitch lines, the same as the diagrams for butt joints with straps of unequal width, to guide the designer in the selection of the proper pitch to permit the joint to be calked.

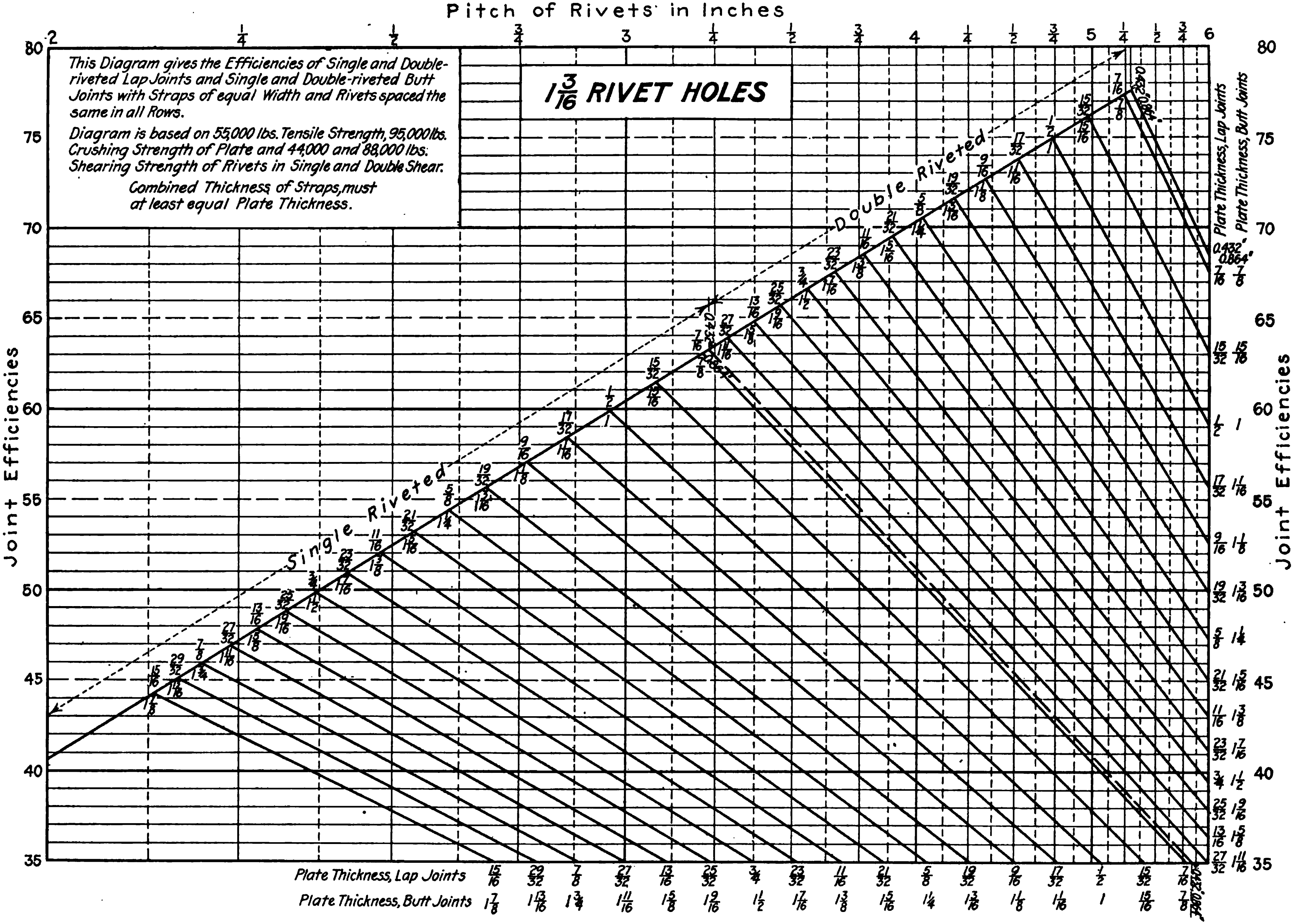
DIAGRAM GIVING SAFE WORKING PRESSURES

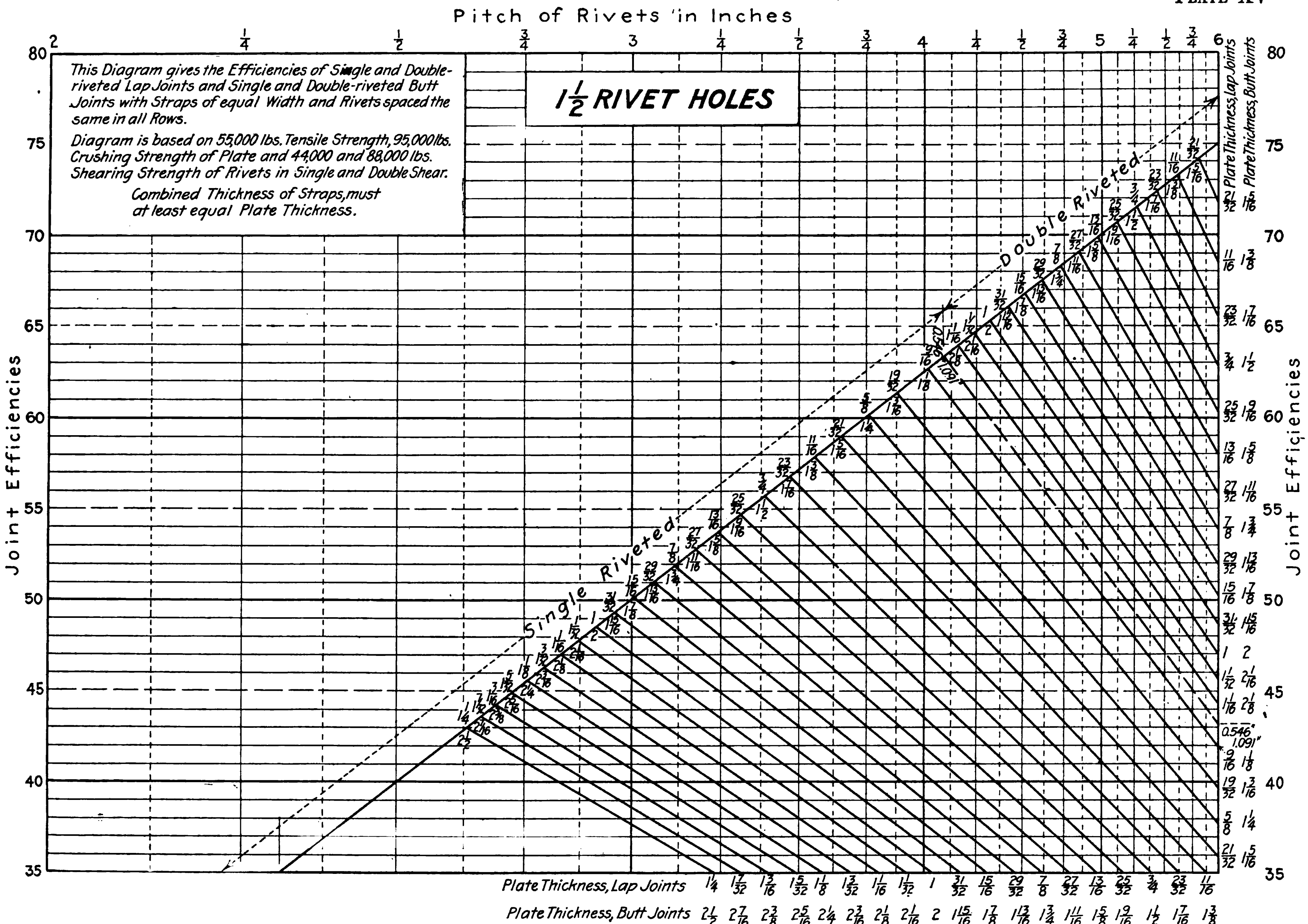
The use of the diagram, Plate 76, is practically self-evident, and it is intended to tell at a glance about how a cylinder should be designed for a given working pressure, or conversely, what pressure may be safely allowed on a vessel already constructed. As will be noted, the pressures given at the bottom on the left side, are divided into 5-lb. increments for working pressures and 25-lb. increments for bursting pressures; however, only every other line has the pressure marked on it, so that the numbered increments are by 10 lb. and 50 lb. The lines denoting joint efficiencies are given in 2 per cent. increments from 30 per cent. to 100 per cent.; also the shell diameters are given in 2-in. increments from 18-in. to 150-in. diameter, and the plate thicknesses are given by $\frac{1}{32}$ in. from ¼ to 1⅜ in. in thickness.

If the diagram is to be used to determine the working pressure that is to be allowed on a cylinder already constructed, the procedure would be as follows. First obtain the joint efficiency, which for the purpose of illustration will be assumed at 82 per cent.; the plate thickness and diameter will be assumed at $\frac{29}{32}$ in. and 72 in. respectively. Starting at the right-hand bottom of the sheet on the line marked $\frac{29}{32}$, follow up this line until the diagonal line for 72-in. diameter is reached, then follow across the sheet, guided by the horizontal lines, until the diagonal line representing 82 per cent. is reached, and from this point follow down the vertical line to the bottom of the diagram and read the

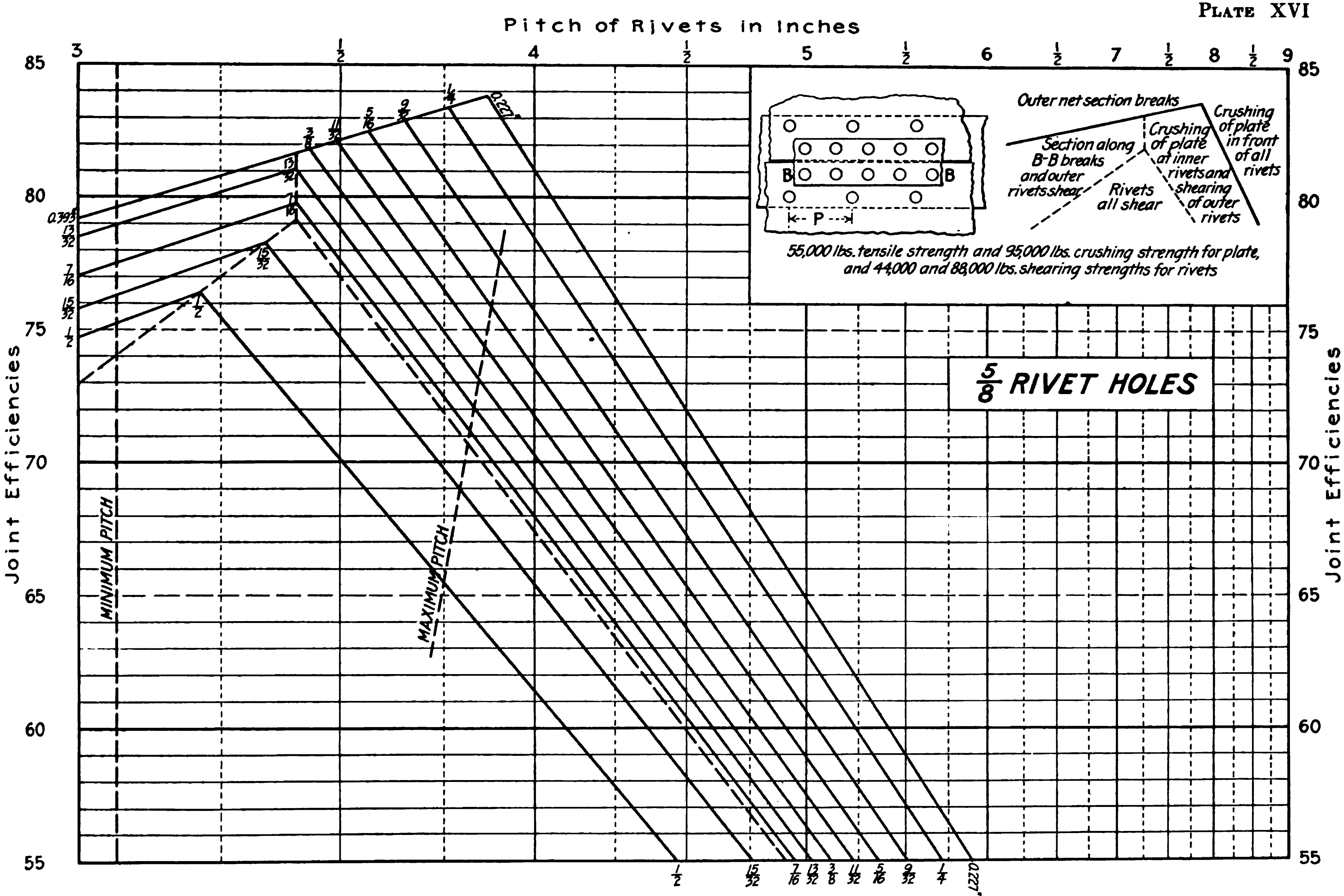
allowable pressure at a factor of safety of five, or the bursting pressure as may be desired. Following this procedure with the values given above, the $^{29}/_{32}$-in. plate-thickness line cuts the diagonal for 72-in. diameter a little above one of the horizontal lines, and following this line across the sheet until it cuts the 82 per cent. efficiency line and selecting a point on this percentage line about the same distance above the horizontal line as was noted on the right side of the sheet, it is seen that the intersection is near the vertical line labelled 230 lb., say at 227 lb. as a safe working pressure at a factor of safety of five, or a bursting pressure of 1,135 lb. It is, of course, understood that this diagram is constructed for 55,000-lb. tensile-strength plate, and it would not serve for any other tensile-strength plate. If the problem was to determine the plate thickness required for a vessel of a given diameter to secure a certain pressure, it would be necessary to assume a joint efficiency, and several trials might be required before the desired results would be reached. For example, assume that it was desired to know what plate thickness would be required for a shell 42 in. in diameter constructed with a double-riveted lap joint, and to be safe for a working pressure of 125 lb. If the designer is at all familiar with the subject, he will realize that the plate thickness required for a vessel under these conditions would not be great, and that it would be possible to secure a joint efficiency, with the form of joint described, of about 70– to 72 per cent. Assuming a joint efficiency of 70 per cent. and starting at the bottom of the left side of the page at 125 lb. working pressure, follow up the line representing this pressure until it intersects the diagonal line for 70 per cent. efficiency and across the sheet to the diagonal line representing 42-in. diameter, when it will be seen that a plate thickness of $^{11}/_{32}$ in. with a joint efficiency of 70 per cent., would give slightly more pressure than the 125 lb. required. If on investigation it was found that the joint efficiency attainable with the plate thickness indicated would not be as high as assumed, a lower efficiency would have to be tried and by the same procedure a new plate thickness could be obtained. Where the values are close or the exact pressure allowable is desired, the values shown by the diagram may be checked by making the usual calculations, but this will not be found necessary in the average case.

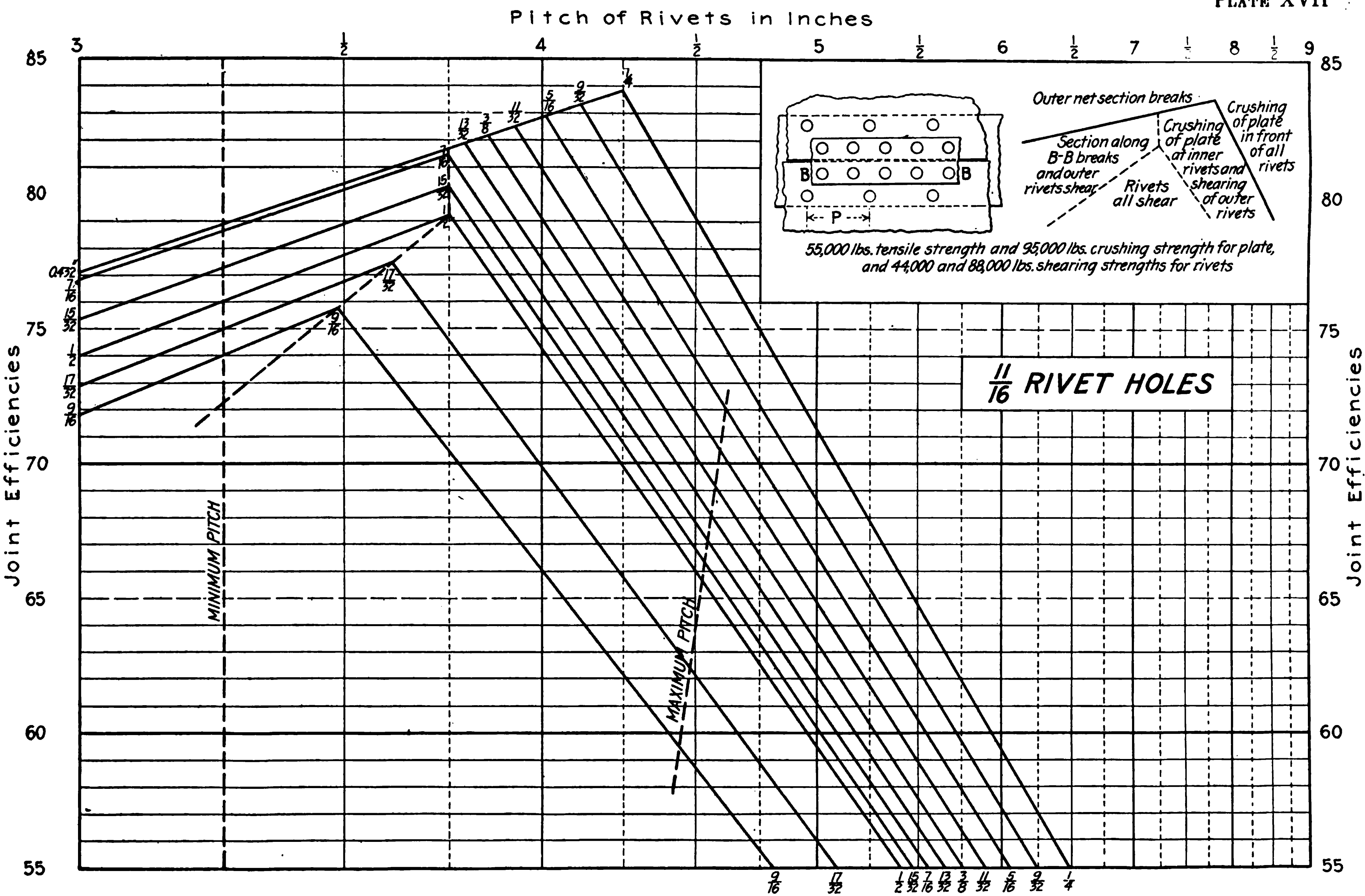

Pitch of Rivets in Inches
This Diagram gives the Efficiencies of Single and Double-riveted Lap Joints and Single and Double-riveted Butt Joints with Straps of equal Width and Rivets spaced the same in all Rows.
Diagram is based on 55,000 lbs. Tensile Strength, 95,000 lbs. Crushing Strength of Plate and 44,000 and 88,000 lbs. Shearing Strength of Rivets in Single and Double Shear.
Combined Thickness of Straps, must at least equal Plate Thickness.
3/4 RIVET HOLES
Single Riveted
Double Riveted
Joint Efficiencies
Plate Thickness, Lap Joints
Plate Thickness, Butt Joints

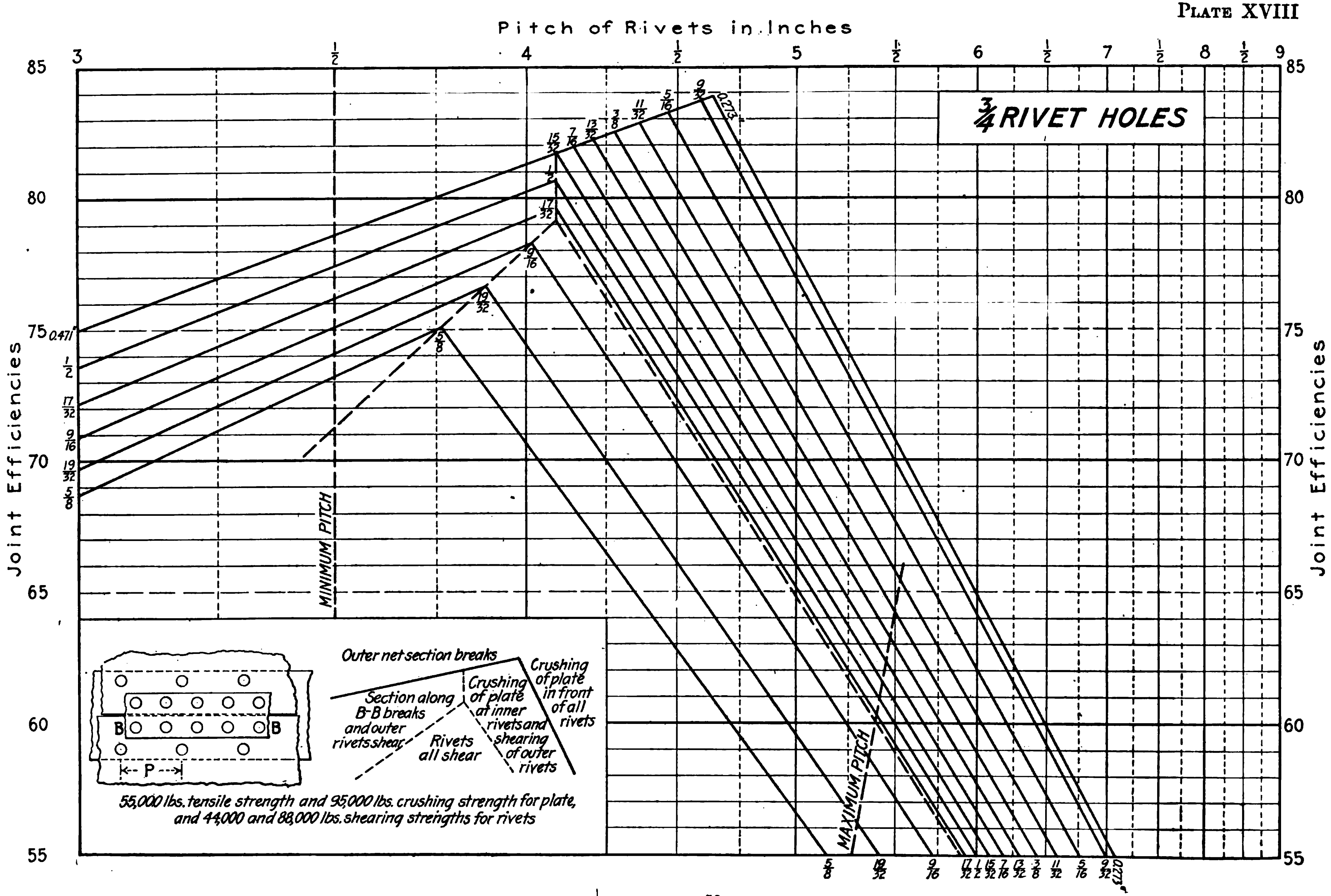

Pitch of Rivets in Inches
This Diagram gives the Efficiencies of Single and Double-riveted Lap Joints and Single and Double-riveted Butt Joints with Straps of equal Width and Rivets spaced the same in all Rows.
Diagram is based on 55,000 lbs. Tensile Strength, 95,000 lbs. Crushing Strength of Plate and 44,000 and 88,000 lbs. Shearing Strength of Rivets in Single and Double Shear.
Combined Thickness of Straps, must at least equal Plate Thickness.
1 3/16 RIVET HOLES
Single Riveted
Double Riveted
Joint Efficiencies
Plate Thickness, Lap Joints
Plate Thickness, Butt Joints

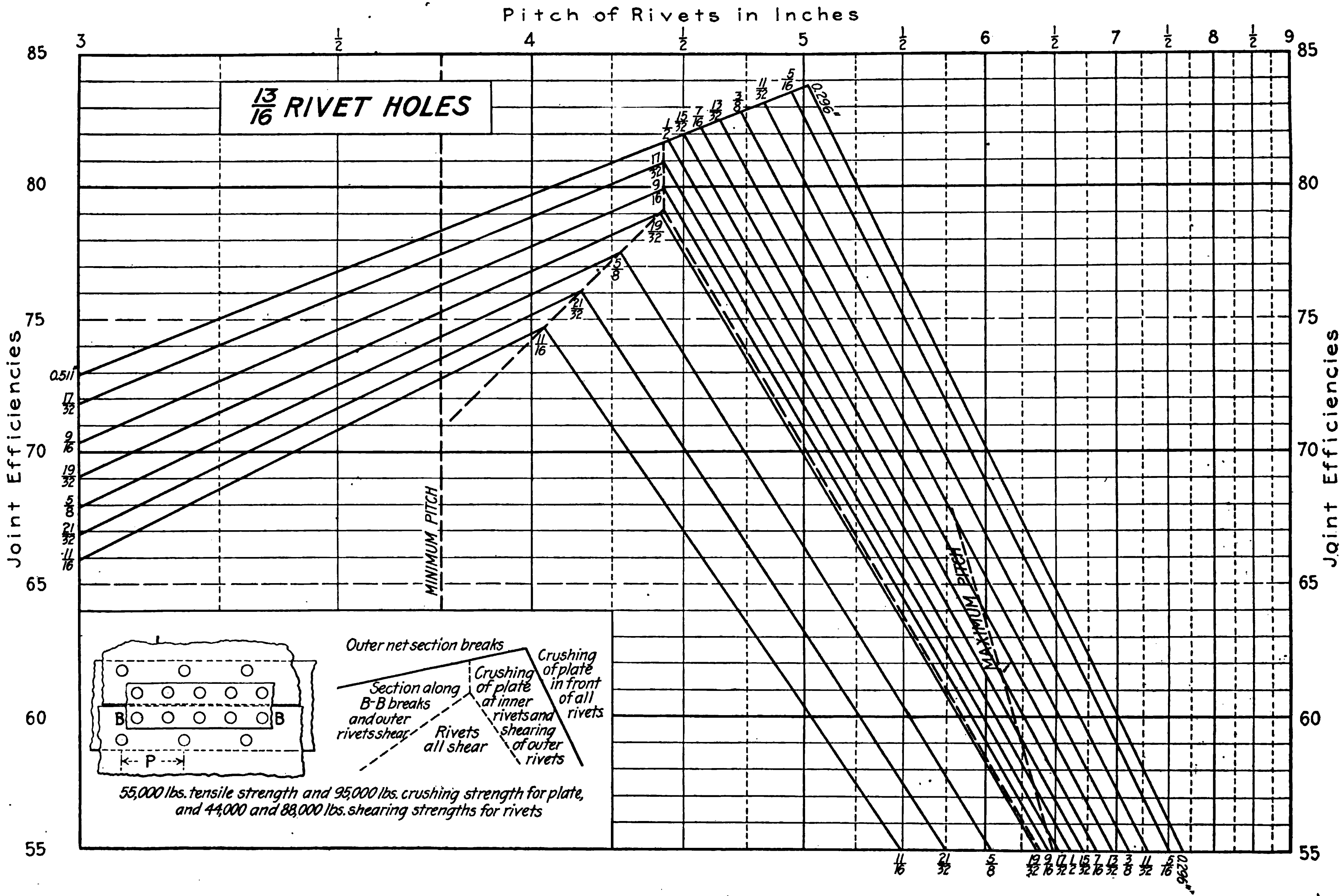


Pitch of Rivets in Inches
This Diagram gives the Efficiencies of Single and Double-riveted Lap Joints and Single and Double-riveted Butt Joints with Straps of equal Width and Rivets spaced the same in all Rows.
Diagram is based on 55,000 lbs. Tensile Strength, 95,000 lbs. Crushing Strength of Plate and 44,000 and 88,000 lbs. Shearing Strength of Rivets in Single and Double Shear.
Combined Thickness of Straps, must at least equal Plate Thickness.
1 1/2 RIVET HOLES
Single Riveted
Double Riveted
Joint Efficiencies
Plate Thickness, Lap Joints
Plate Thickness, Butt Joints
0.546"
1.091"

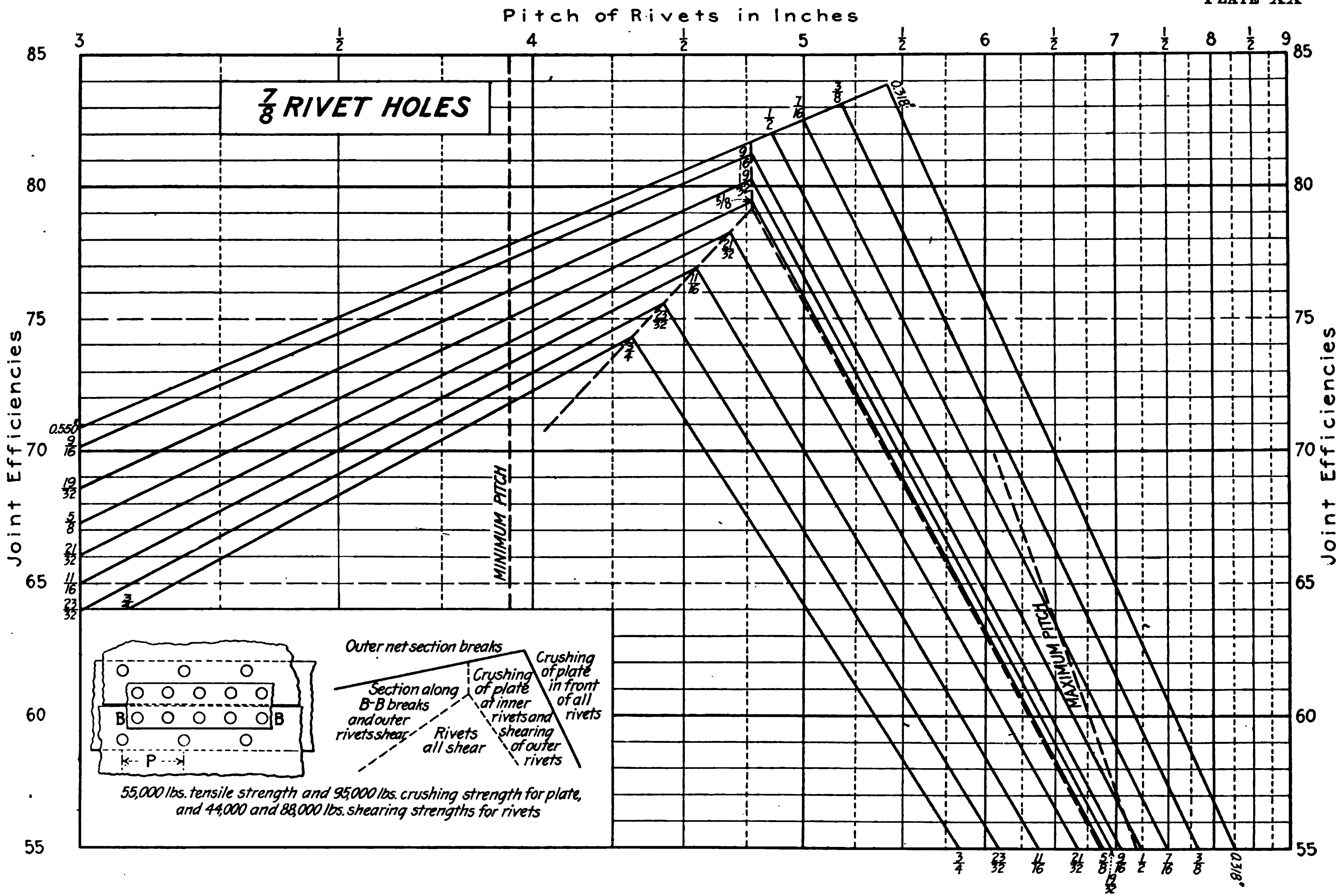

Pitch of Rivets in Inches
Joint Efficiencies
MINIMUM PITCH
MAXIMUM PITCH
5/8 RIVET HOLES
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets

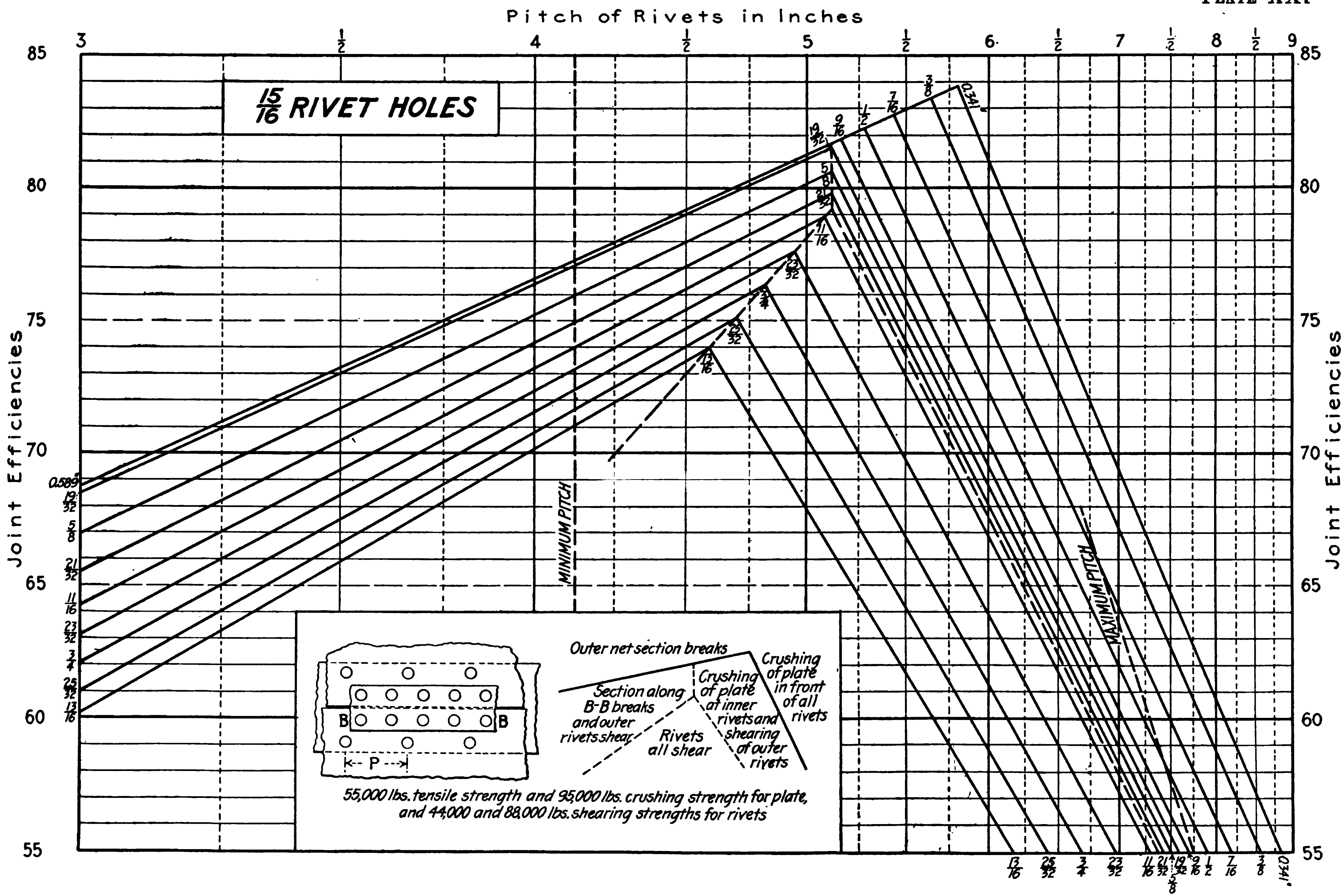

Pitch of Rivets in Inches
Joint Efficiencies
Outer net section breaks
Crushing of plate in front of all rivets
Section along B-B breaks and outer rivets shear
Crushing of plate at inner rivets and shearing of outer rivets
Rivets all shear
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets
11/16 RIVET HOLES
MINIMUM PITCH
MAXIMUM PITCH

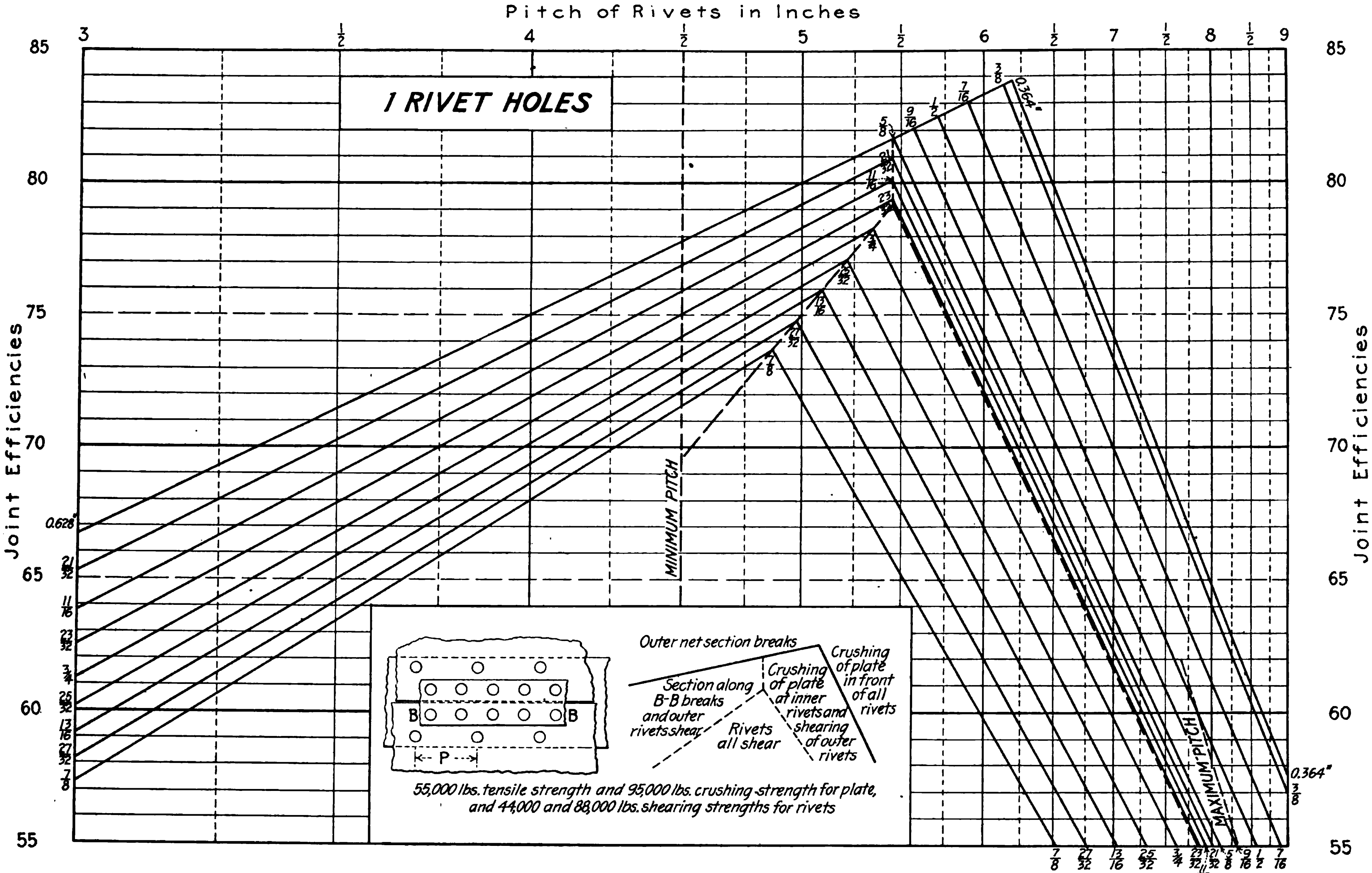

Pitch of Rivets in Inches
3
1/2
4
1/2
5
1/2
6
1/2
7
1/2
8
1/2
9
85
80
75
70
65
60
55
Joint Efficiencies
3/4 RIVET HOLES
0.471
1/2
17/32
9/16
19/32
5/8
0.273
MINIMUM PITCH
MAXIMUM PITCH
Outer net section breaks
Section along B-B breaks and outer rivets shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
Rivets all shear
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets

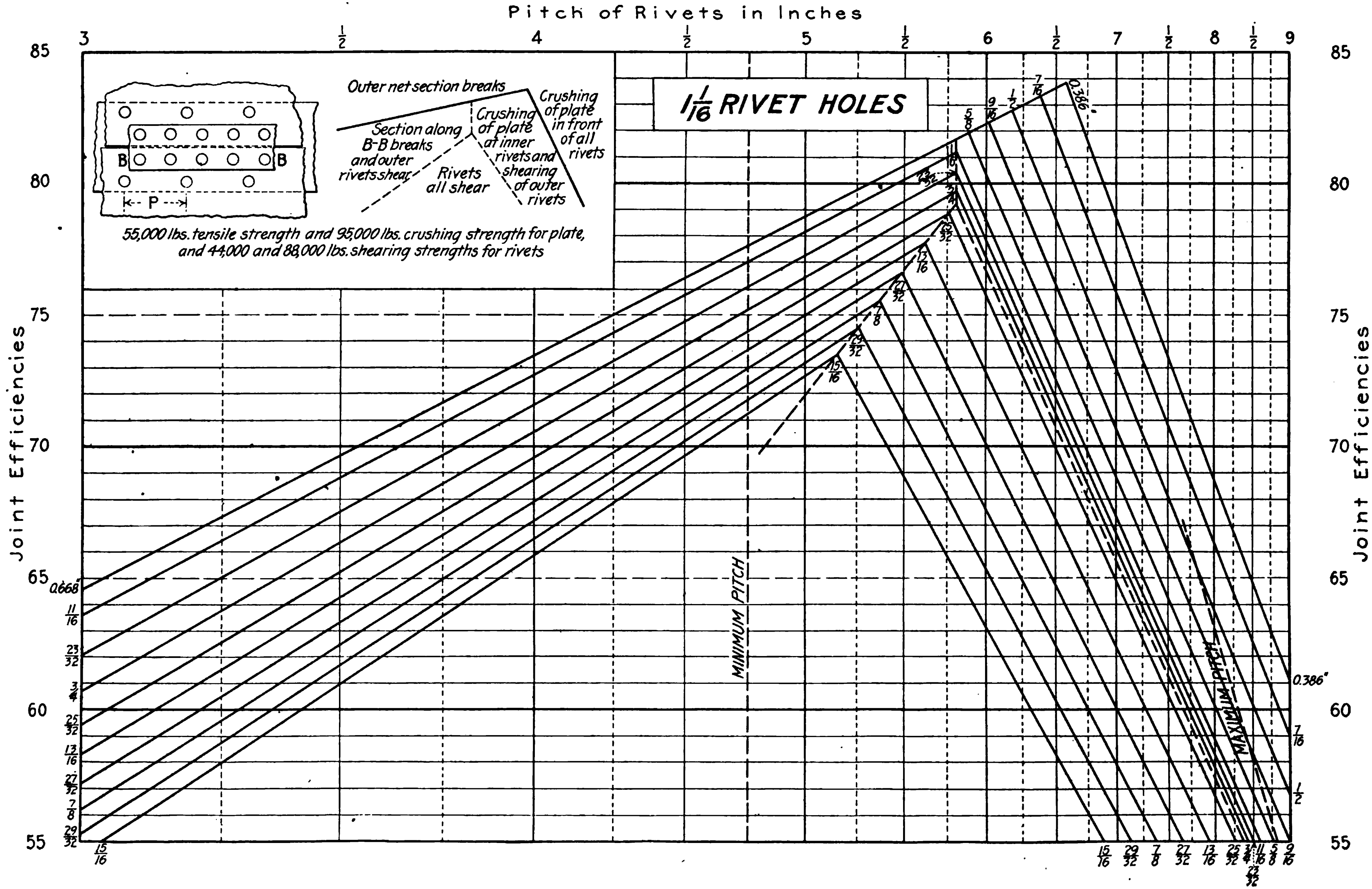


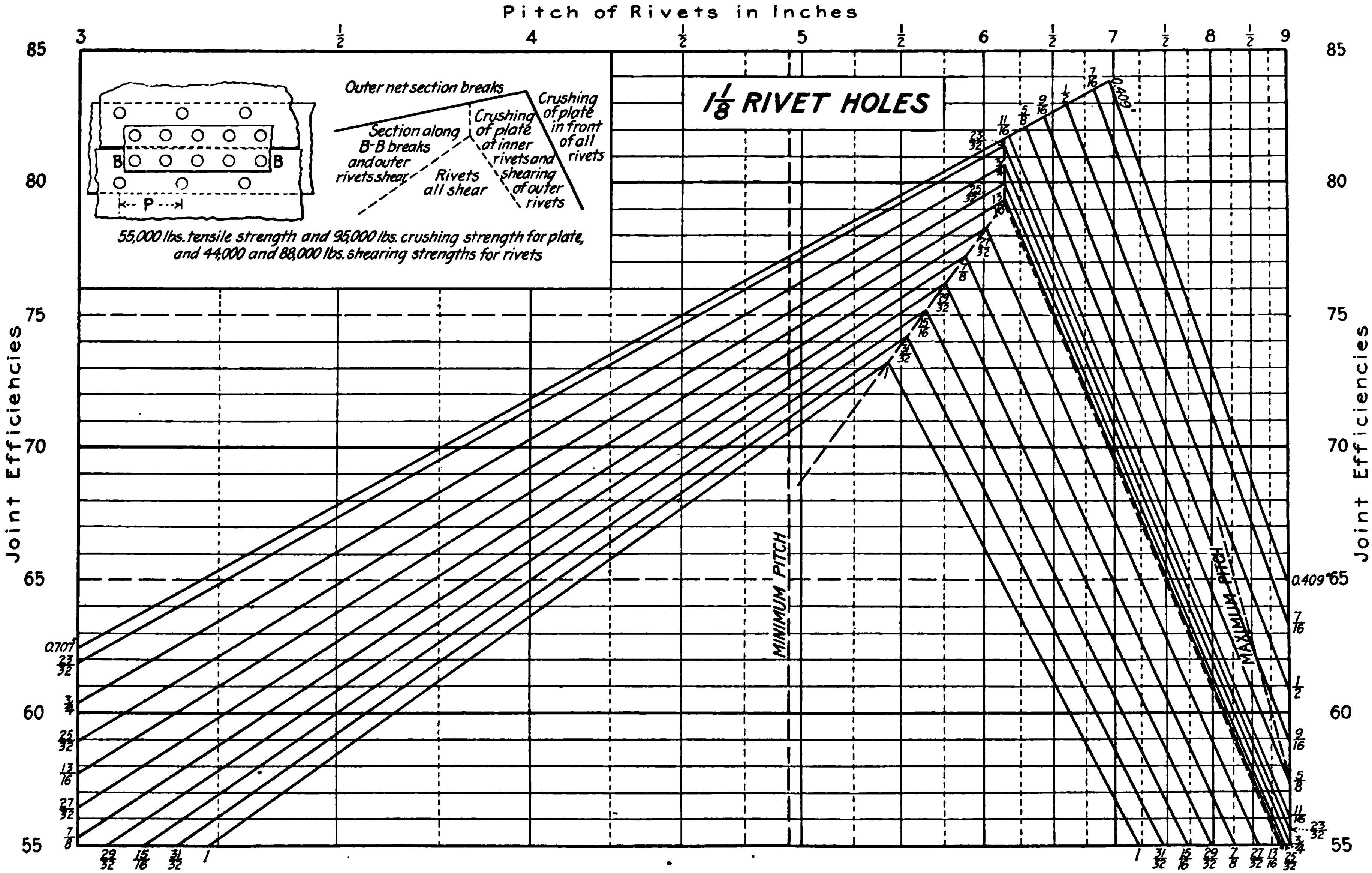
Pitch of Rivets in Inches
Joint Efficiencies
13/16 RIVET HOLES
MINIMUM PITCH
MAXIMUM PITCH
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets


Pitch of Rivets in Inches
7/8 RIVET HOLES
Joint Efficiencies
MINIMUM PITCH
MAXIMUM PITCH
Outer net section breaks
Section along B-B breaks and outer rivets shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
Rivets all shear
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets

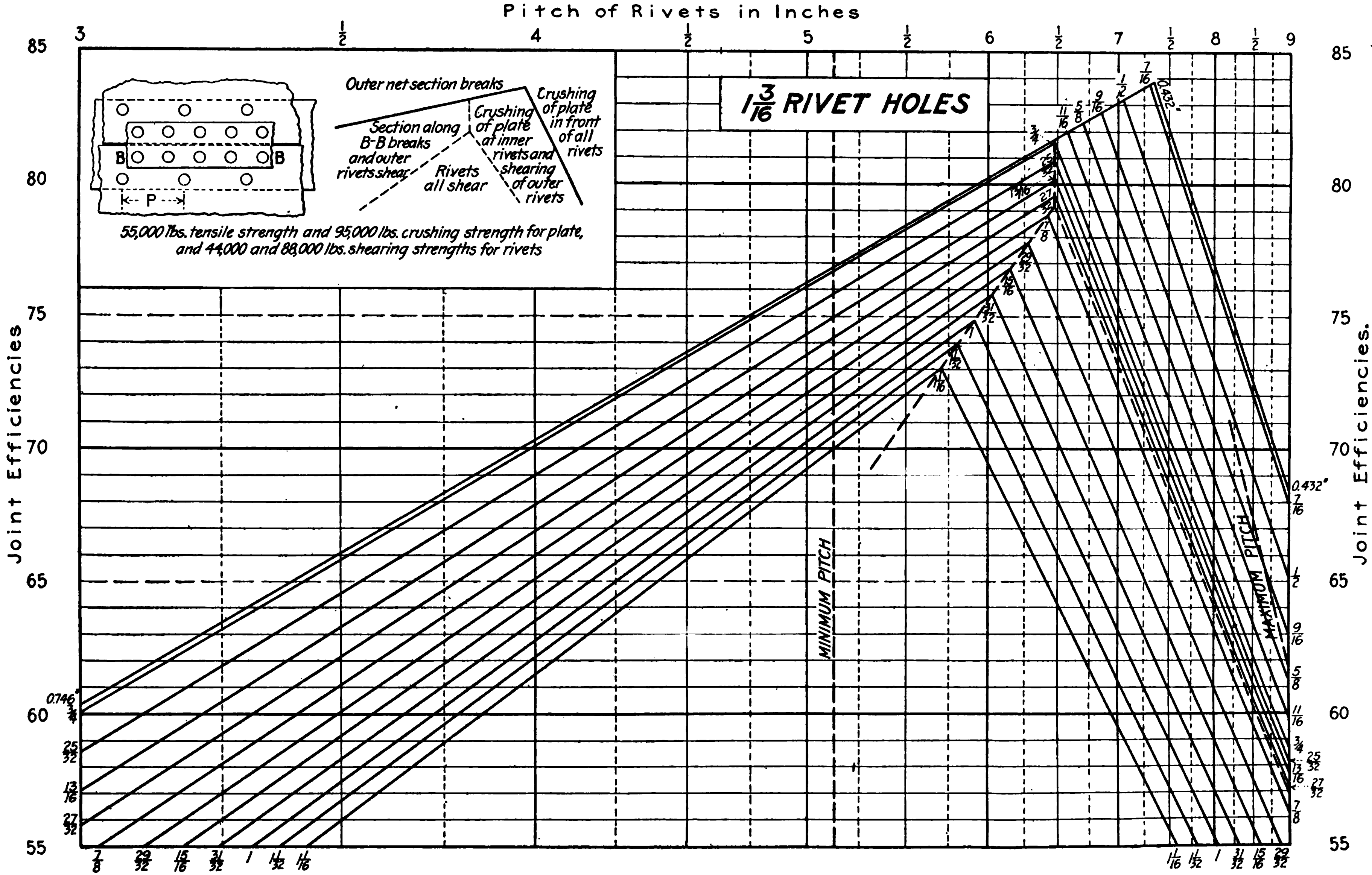

Pitch of Rivets in Inches
Joint Efficiencies
15/16 RIVET HOLES
MINIMUM PITCH
MAXIMUM PITCH
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets

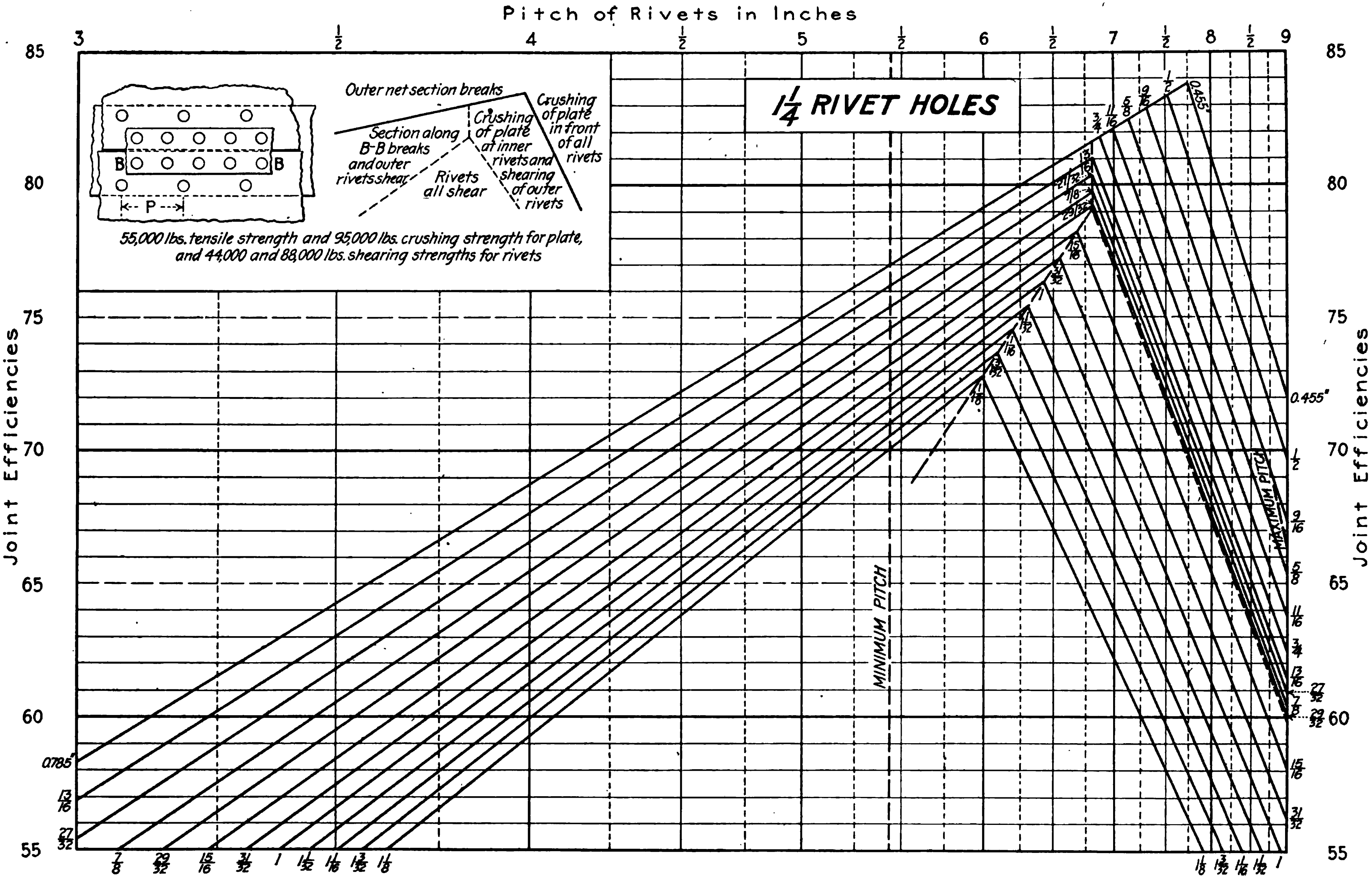

Pitch of Rivets in Inches
1 RIVET HOLES
Joint Efficiencies
MINIMUM PITCH
MAXIMUM PITCH
0.628"
0.364"
Outer net section breaks
Section along B-B breaks and outer rivets shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
Rivets all shear
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets

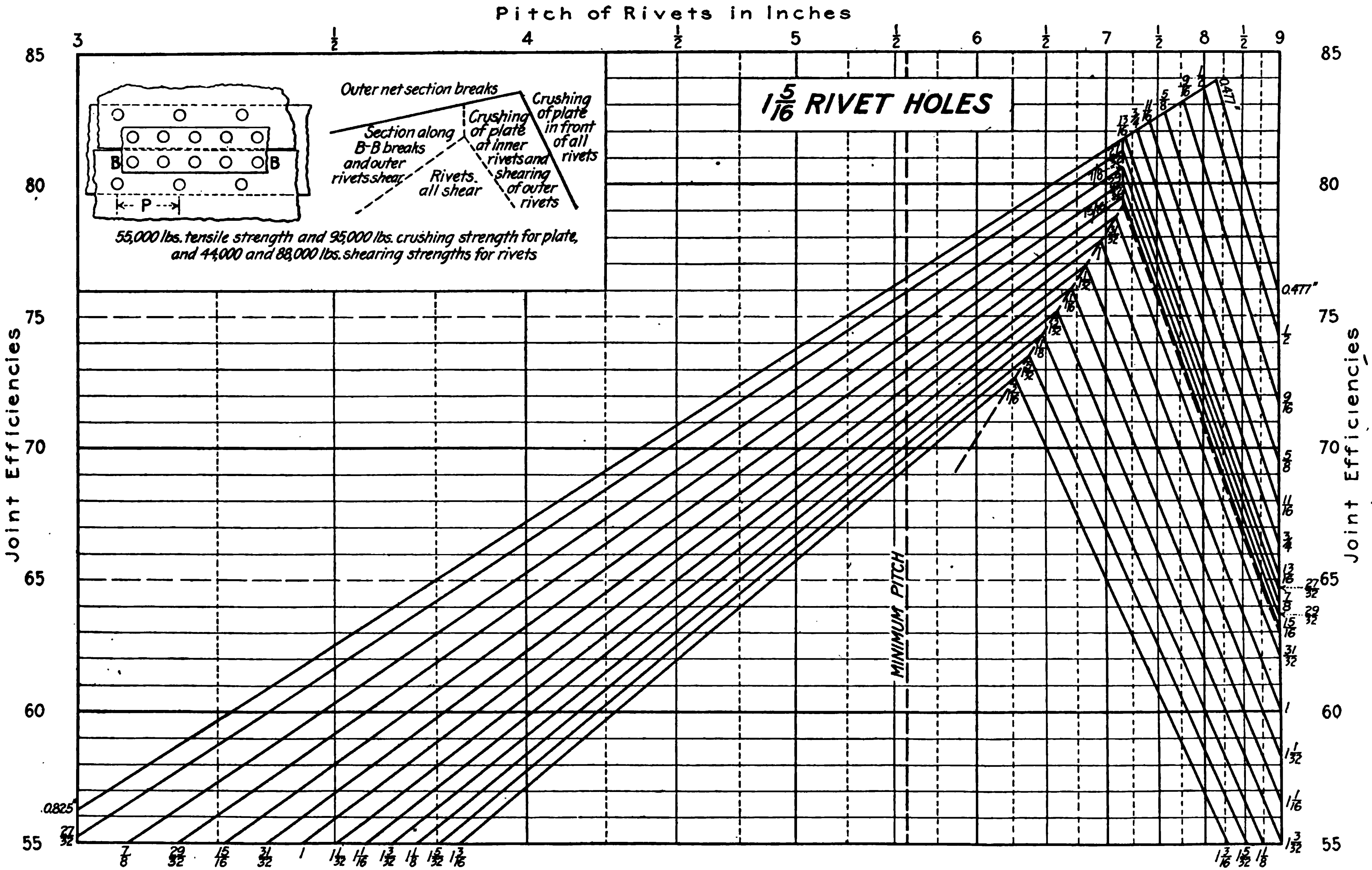

Pitch of Rivets in Inches
3
1/2
4
1/2
5
1/2
6
1/2
7
1/2
8
1/2
9
Joint Efficiencies
85
80
75
70
65
60
55
1 1/16 RIVET HOLES
Outer net section breaks
Section along B-B breaks and outer rivets shear
Crushing of plate at inner rivets and shearing of outer rivets
Rivets all shear
Crushing of plate in front of all rivets
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets
MINIMUM PITCH
MAXIMUM PITCH
0.668"
0.386"
11/16
23/32
3/4
25/32
13/16
27/32
7/8
29/32
15/16
5/8
9/16
1/2
7/16

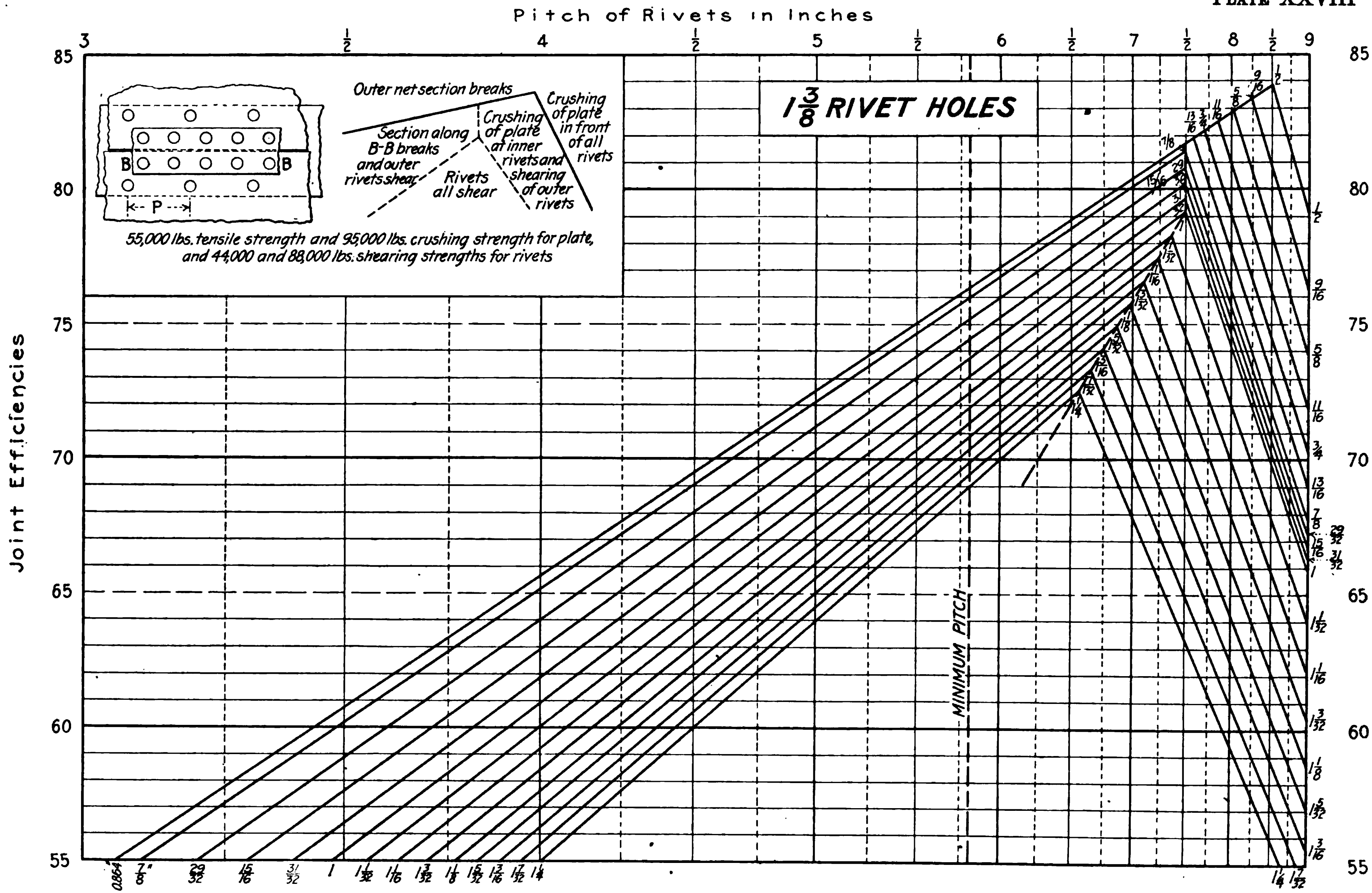


Pitch of Rivets in Inches
Joint Efficiencies
1 1/8 RIVET HOLES
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets
MINIMUM PITCH
MAXIMUM PITCH

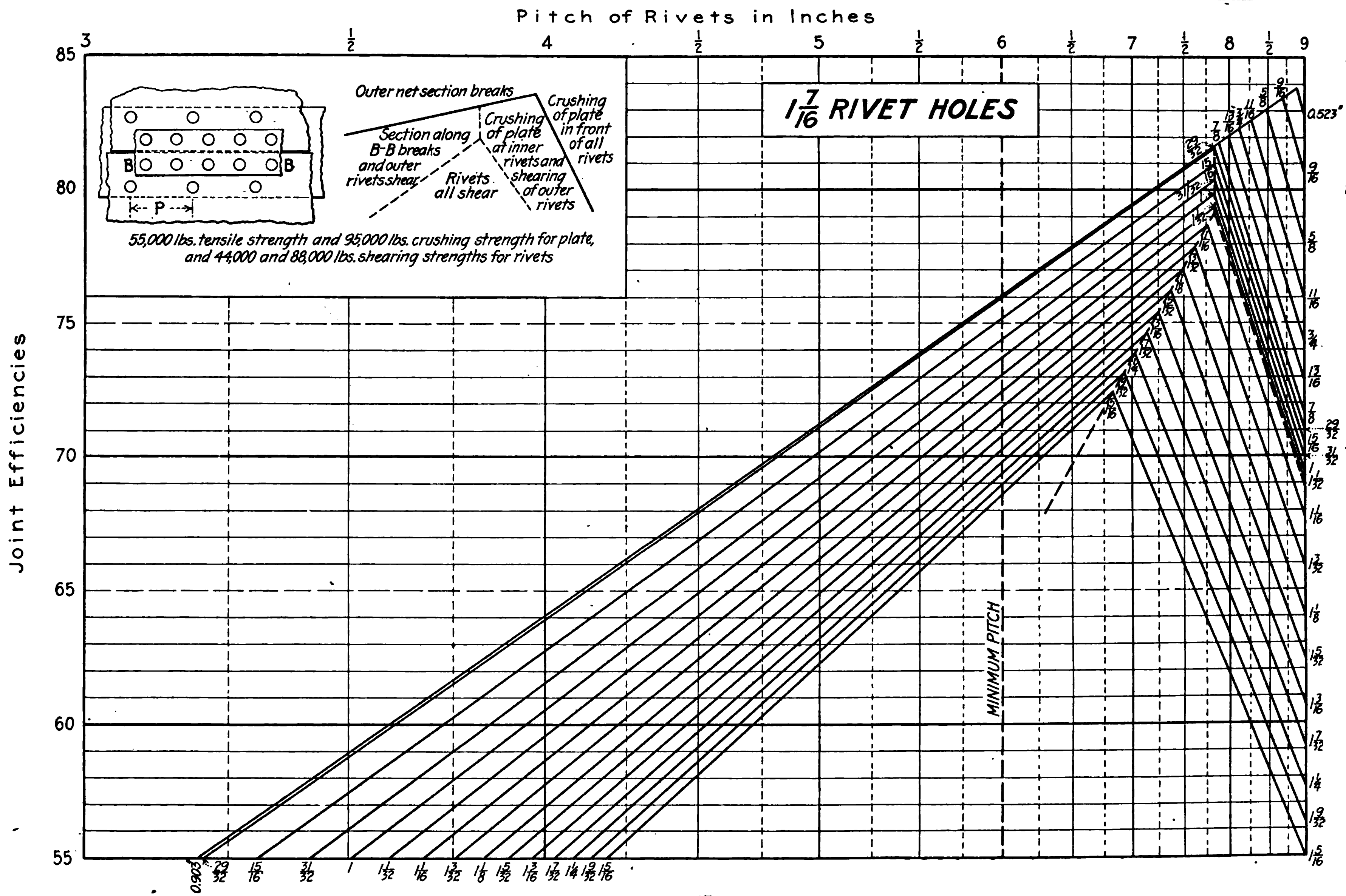

Pitch of Rivets in Inches
Joint Efficiencies
Joint Efficiencies.
1 3/16 RIVET HOLES
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets
MINIMUM PITCH
MAXIMUM PITCH
0.746"
0.432"

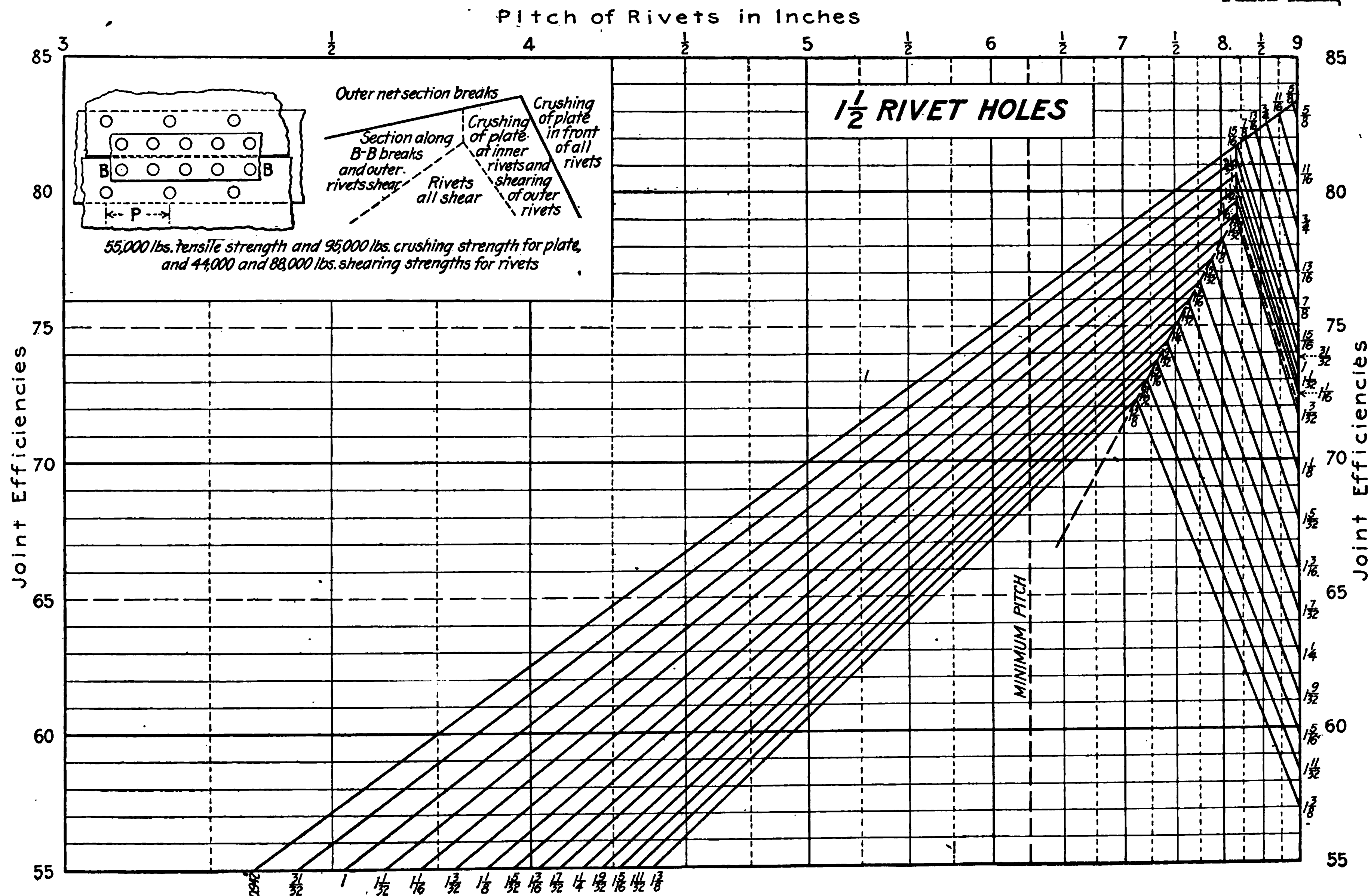

Pitch of Rivets in Inches
Joint Efficiencies
1 1/4 RIVET HOLES
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets
MINIMUM PITCH
MAXIMUM PITCH

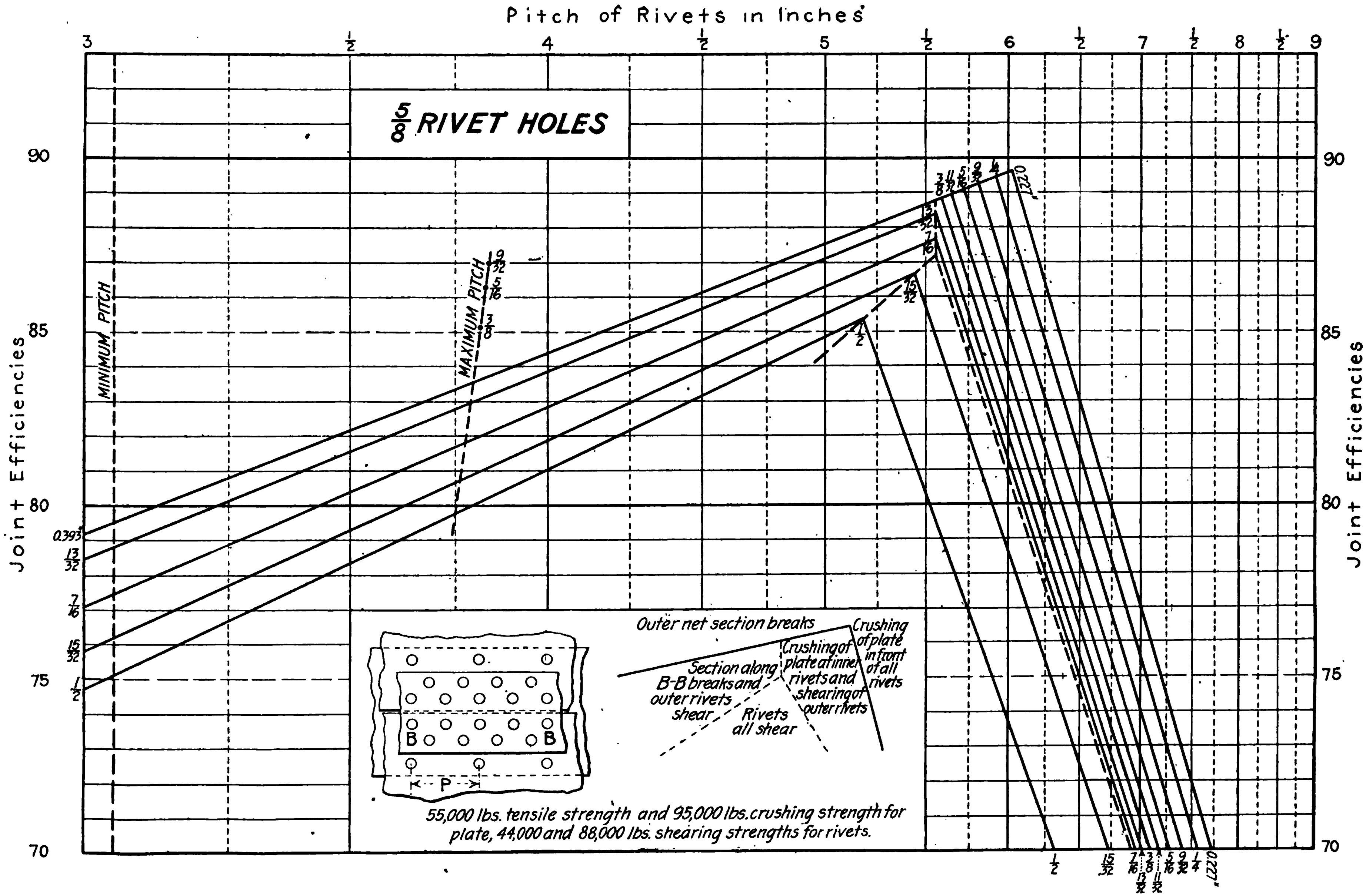

Pitch of Rivets in Inches
Joint Efficiencies
1 5/16 RIVET HOLES
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets
MINIMUM PITCH
B
B
P

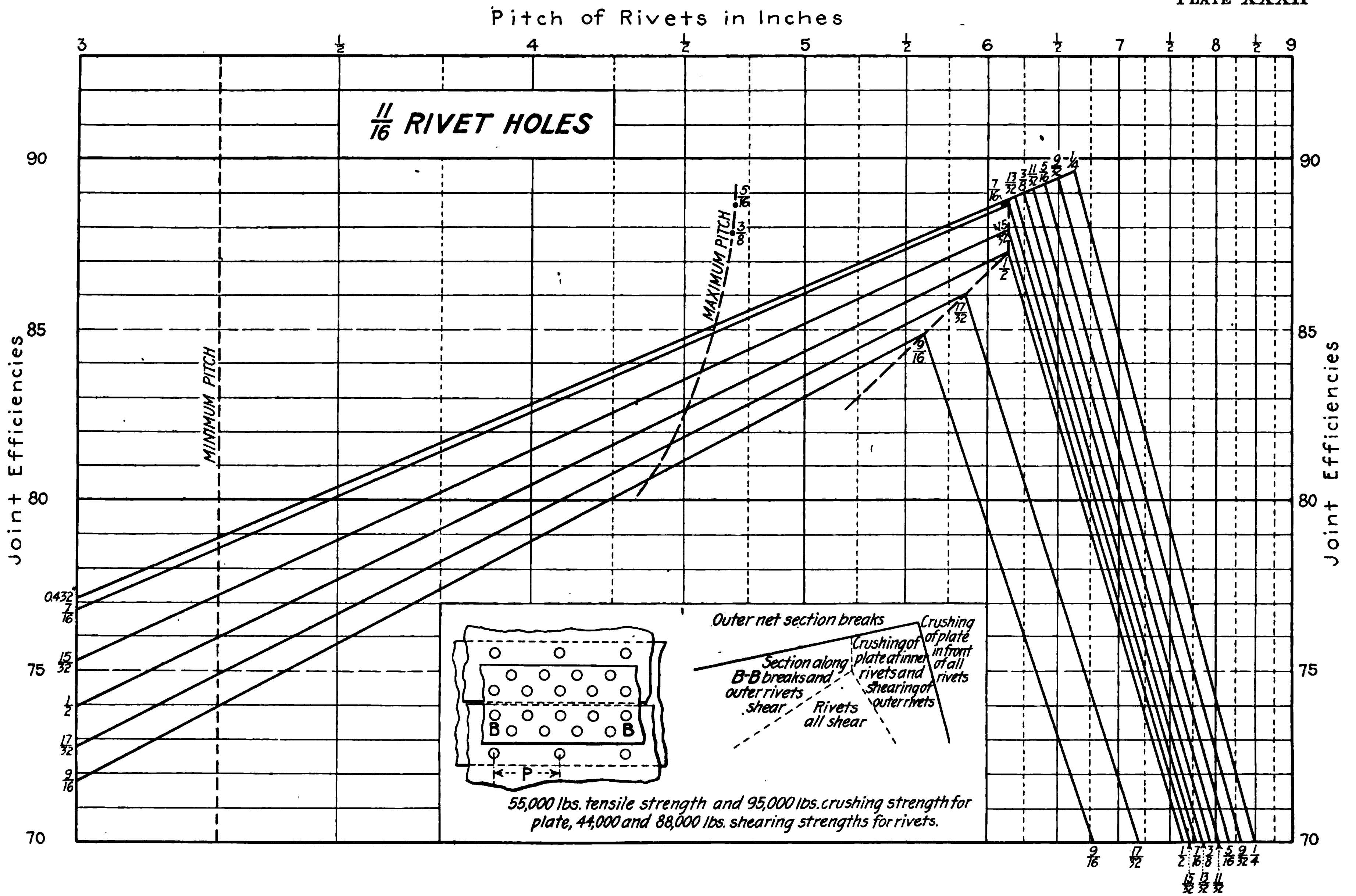


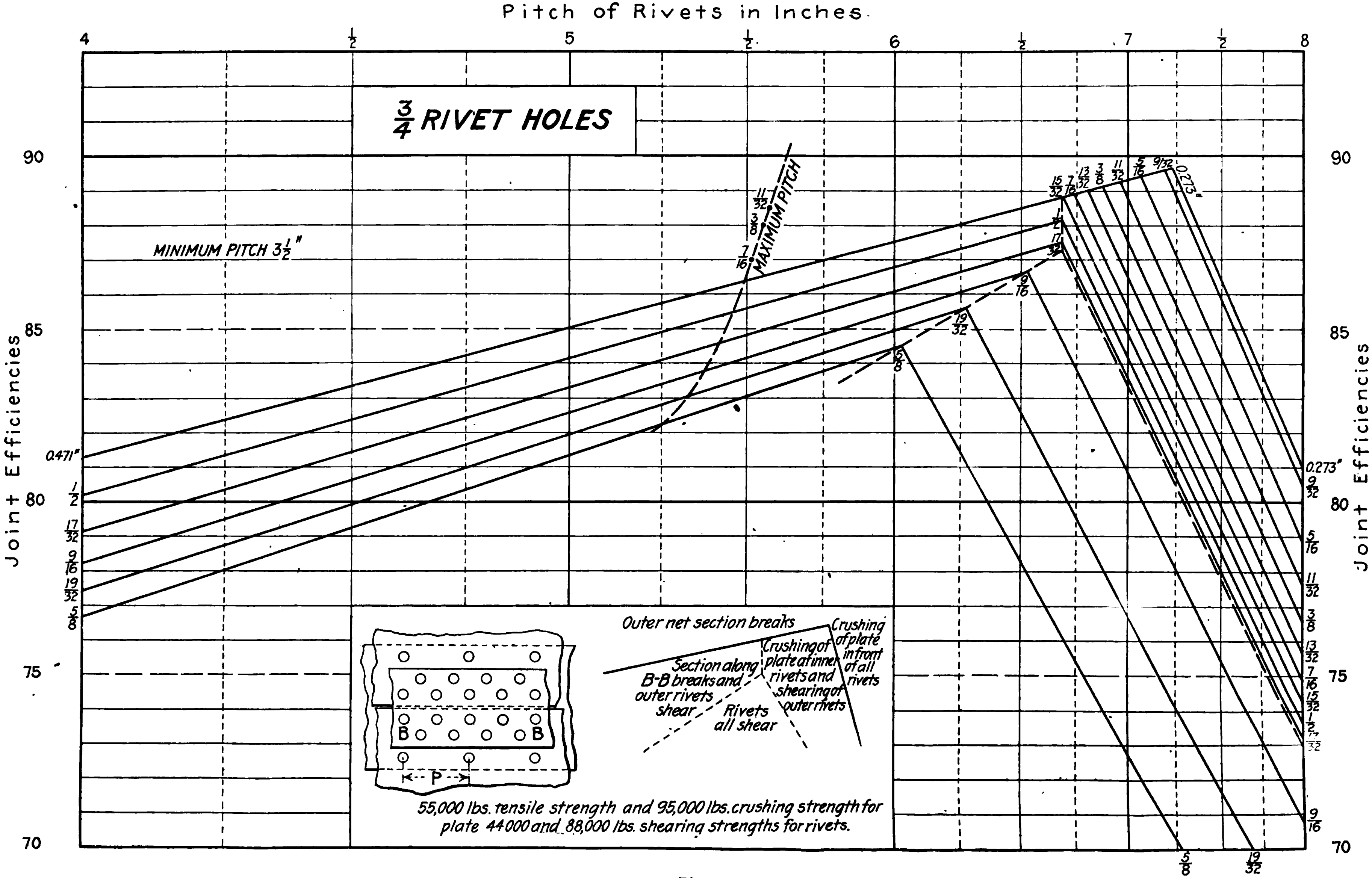
Pitch of Rivets in Inches
Joint Efficiencies
1 3/8 RIVET HOLES
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets
MINIMUM PITCH


Pitch of Rivets in Inches
Joint Efficiencies
1 7/16 RIVET HOLES
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets
MINIMUM PITCH
0.523"
0.903"

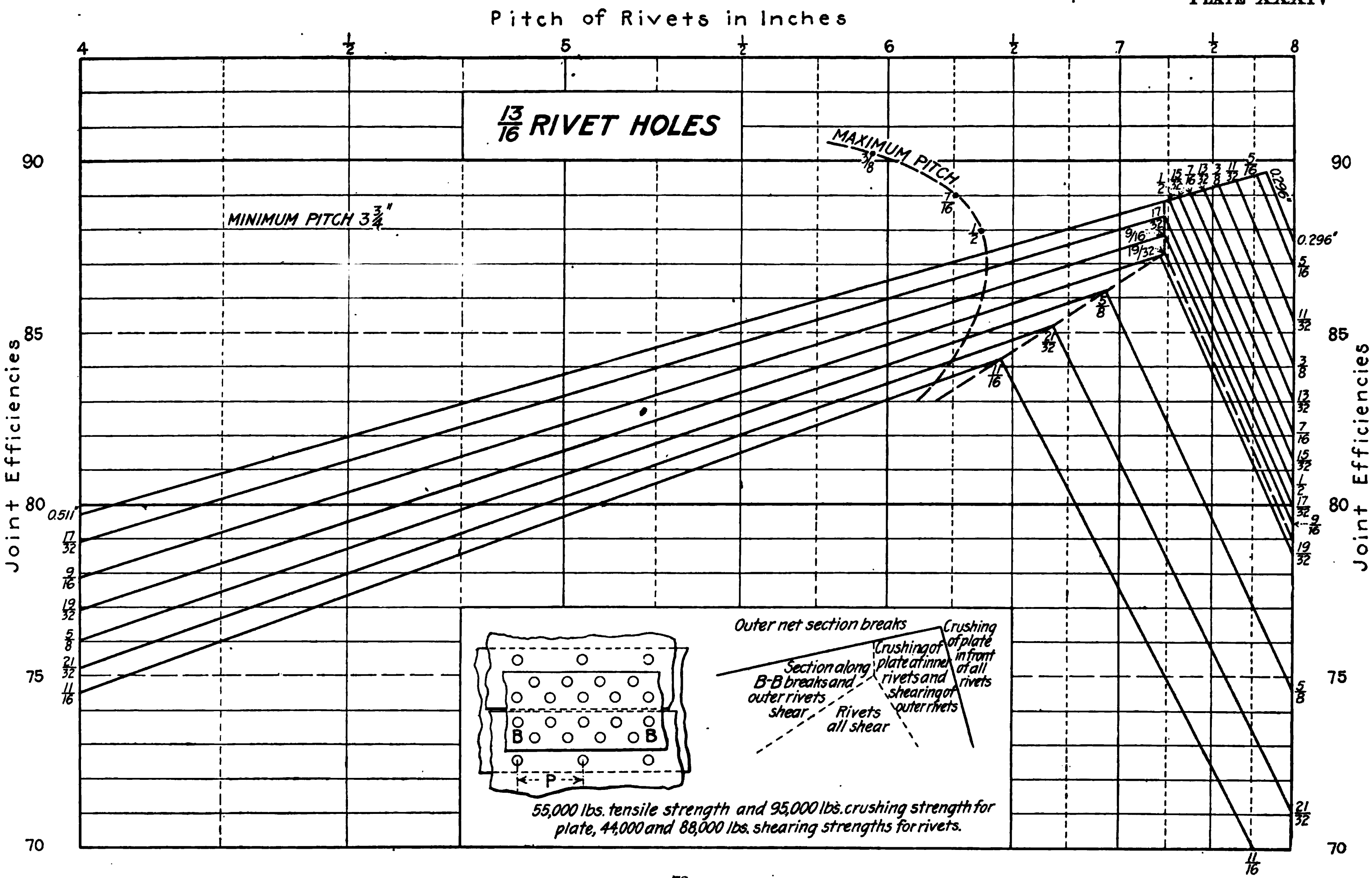

Pitch of Rivets in Inches
Joint Efficiencies
1 1/2 RIVET HOLES
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, and 44,000 and 88,000 lbs. shearing strengths for rivets
MINIMUM PITCH

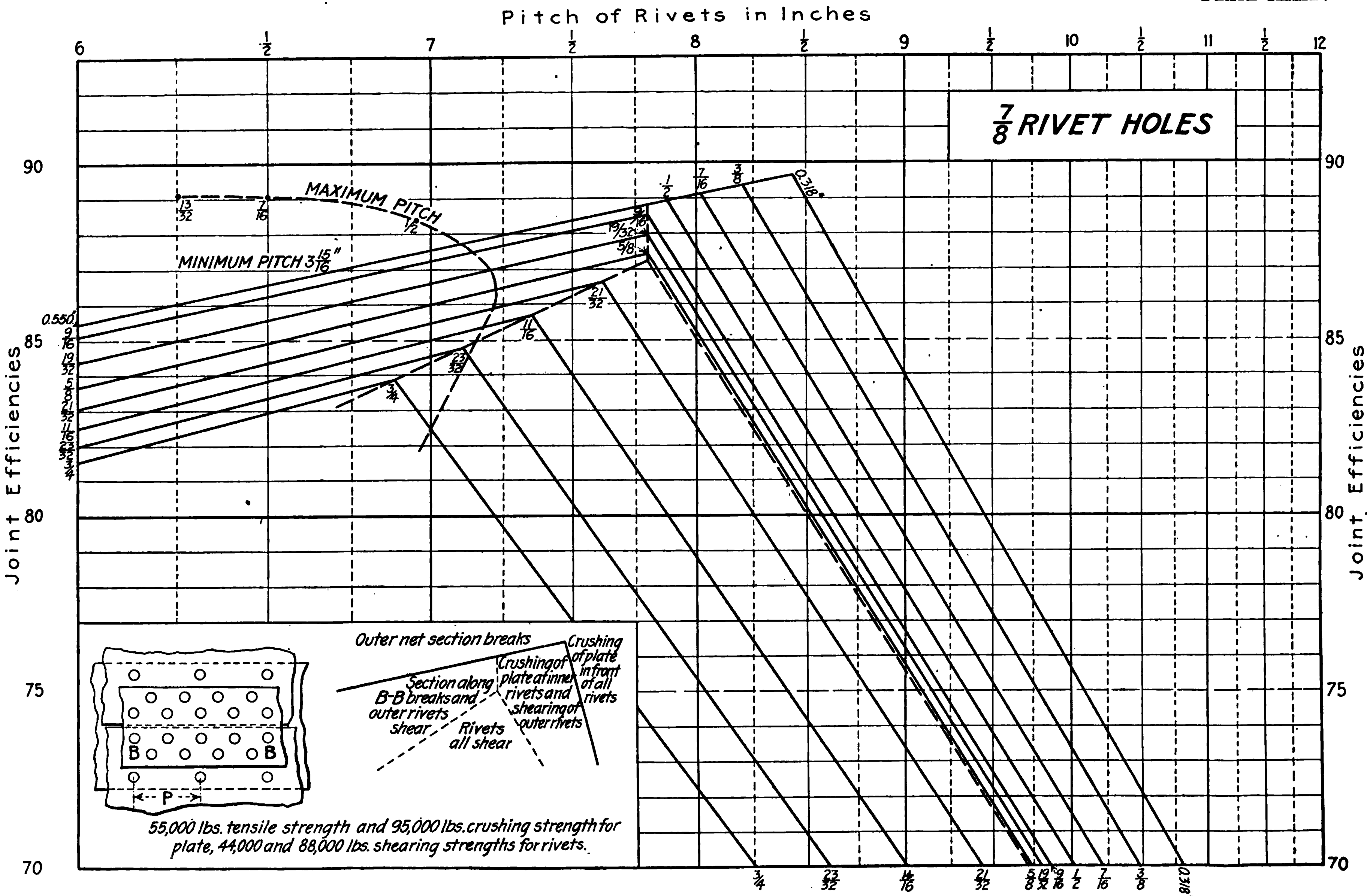

Pitch of Rivets in Inches
5/8 RIVET HOLES
Joint Efficiencies
MINIMUM PITCH
MAXIMUM PITCH
Outer net section breaks
Crushing of plate in front of all rivets
Crushing of plate at inner rivets and shearing of outer rivets
Section along B-B breaks and outer rivets shear
Rivets all shear
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.


Pitch of Rivets in Inches
3
1/2
4
1/2
5
1/2
6
1/2
7
1/2
8
1/2
9
11/16 RIVET HOLES
Joint Efficiencies
90
85
80
75
70
0.432
7/16
15/32
1/2
17/32
9/16
MINIMUM PITCH
MAXIMUM PITCH
15/16
3/8
13/32
3/8
11/32
5/16
9/32
1/4
15/32
17/32
Outer net section breaks
Crushing of plate in front of all rivets
Crushing of plate at inner rivets and shearing of outer rivets
Section along B-B breaks and outer rivets shear
Rivets all shear
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.

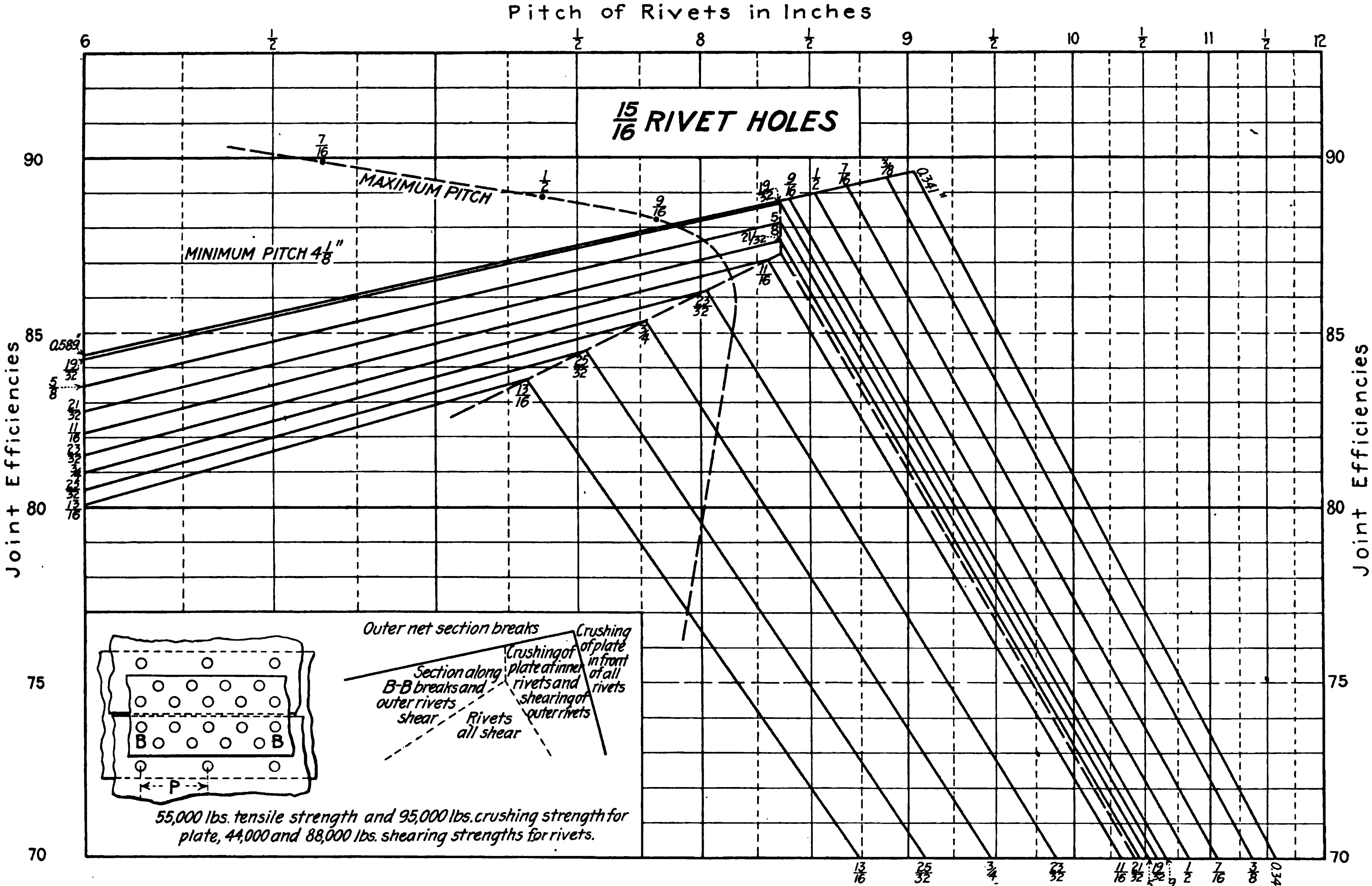


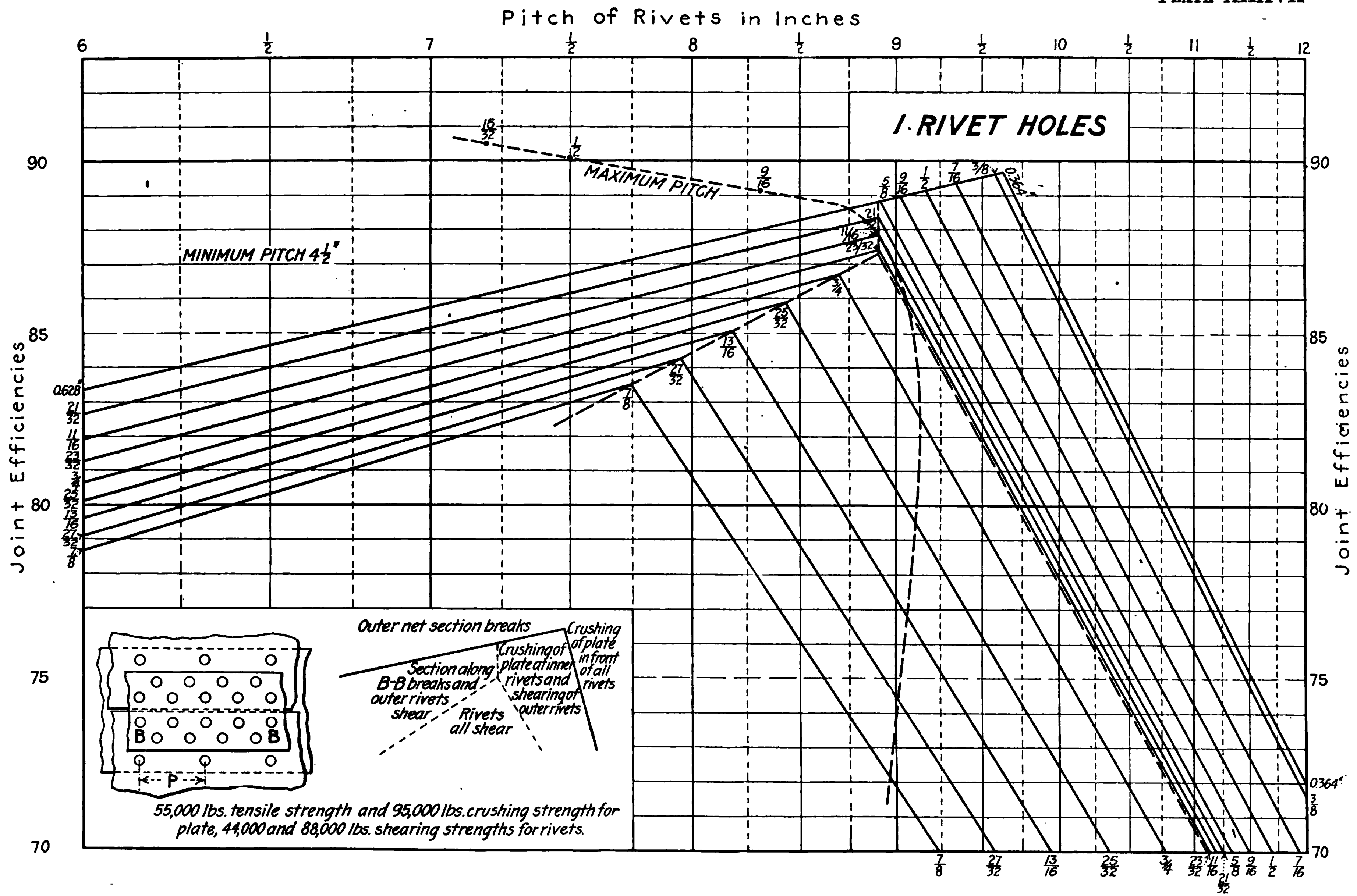
Pitch of Rivets in Inches
4
1/2
5
1/2
6
1/2
7
1/2
8
3/4 RIVET HOLES
MINIMUM PITCH 3 1/2"
MAXIMUM PITCH
Joint Efficiencies
90
85
80
75
70
0.471"
0.273"
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate 44000 and 88,000 lbs. shearing strengths for rivets.

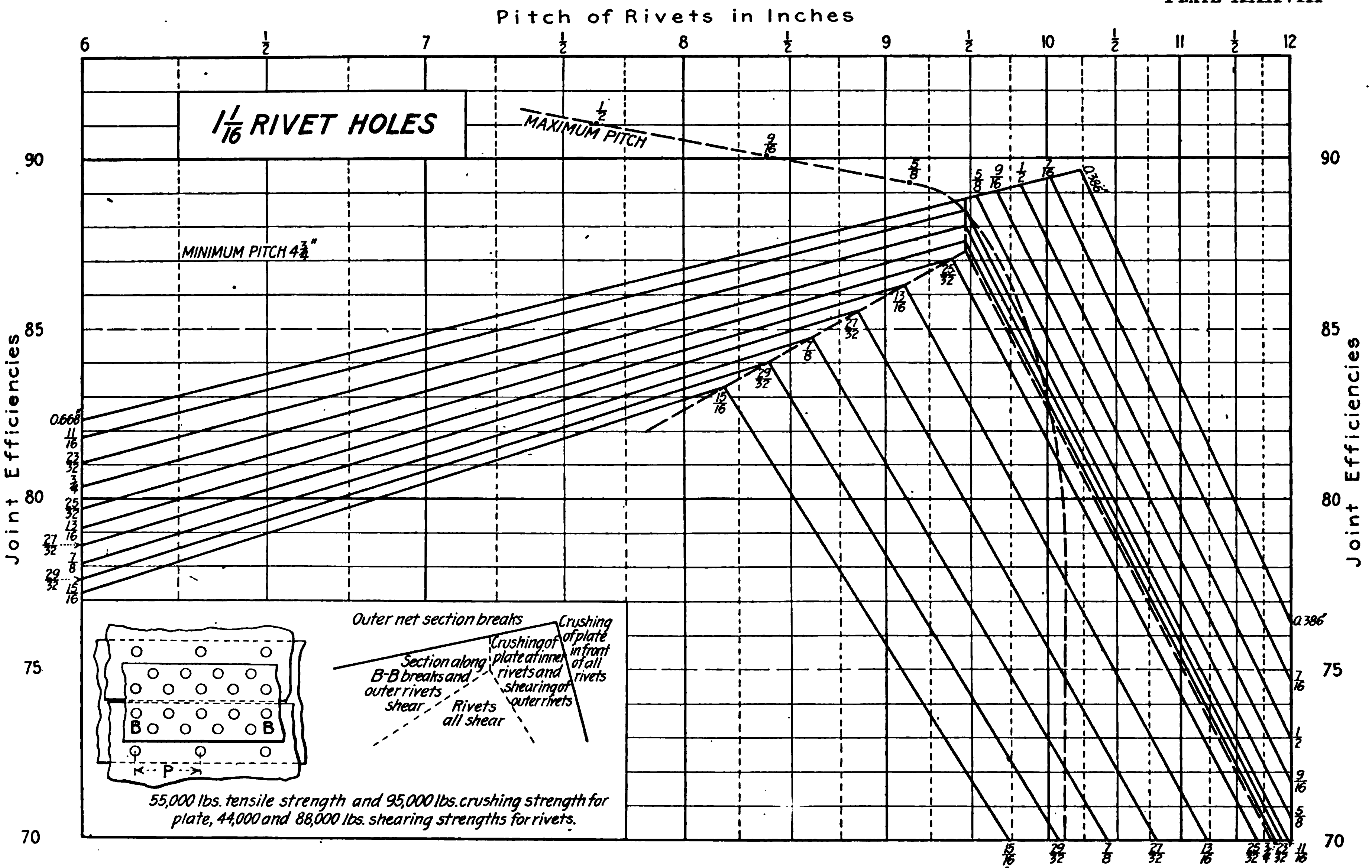

Pitch of Rivets in Inches
4
1/2
5
1/2
6
1/2
7
1/2
8
13/16 RIVET HOLES
MINIMUM PITCH 3 3/4"
MAXIMUM PITCH
Joint Efficiencies
90
85
80
75
70
0.511"
17/32
9/16
19/32
5/8
21/32
11/16
0.296"
5/16
11/32
3/8
13/32
7/16
15/32
1/2
Outer net section breaks
Section along B-B breaks and outer rivets shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
Rivets all shear
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.

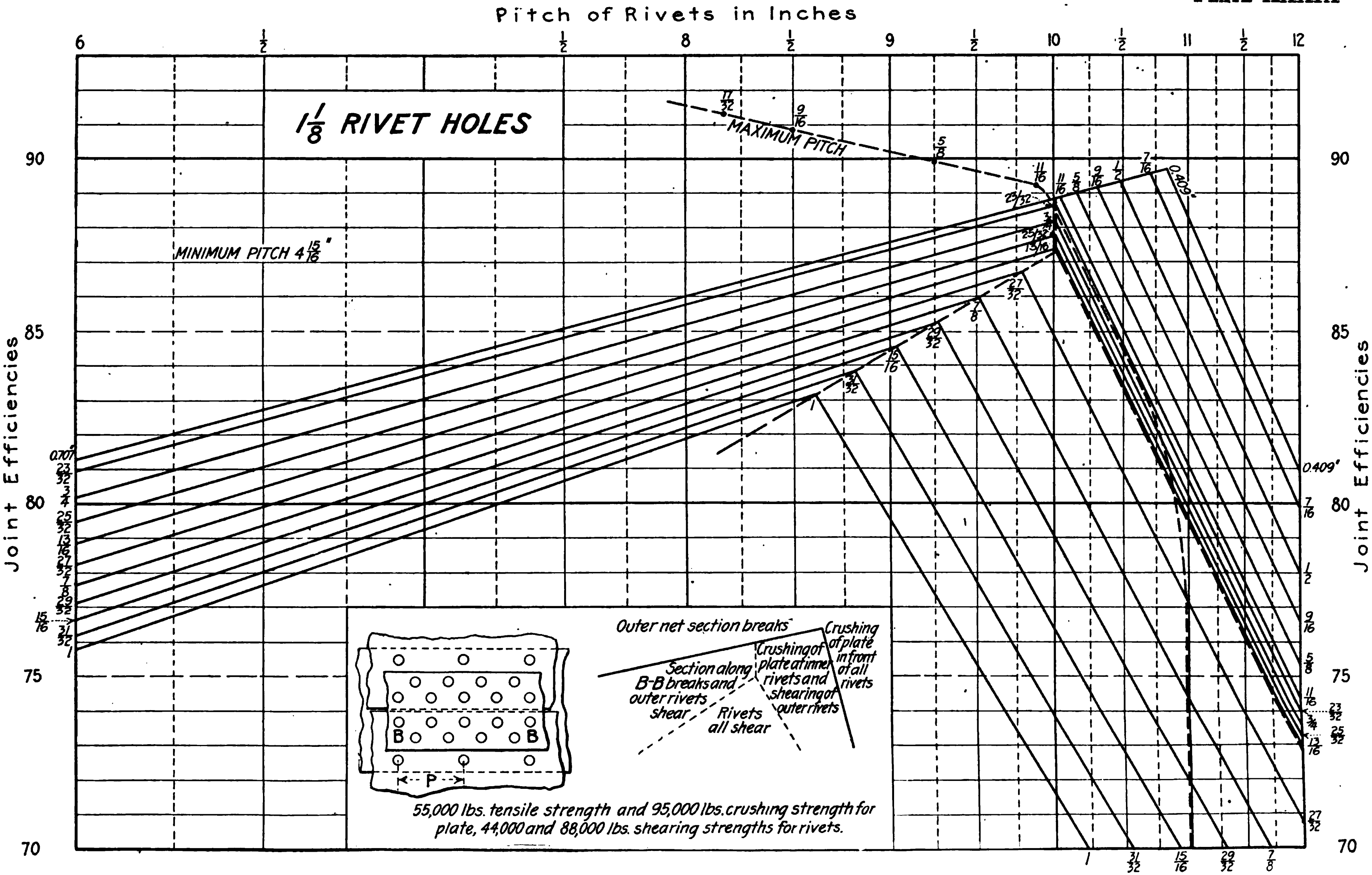


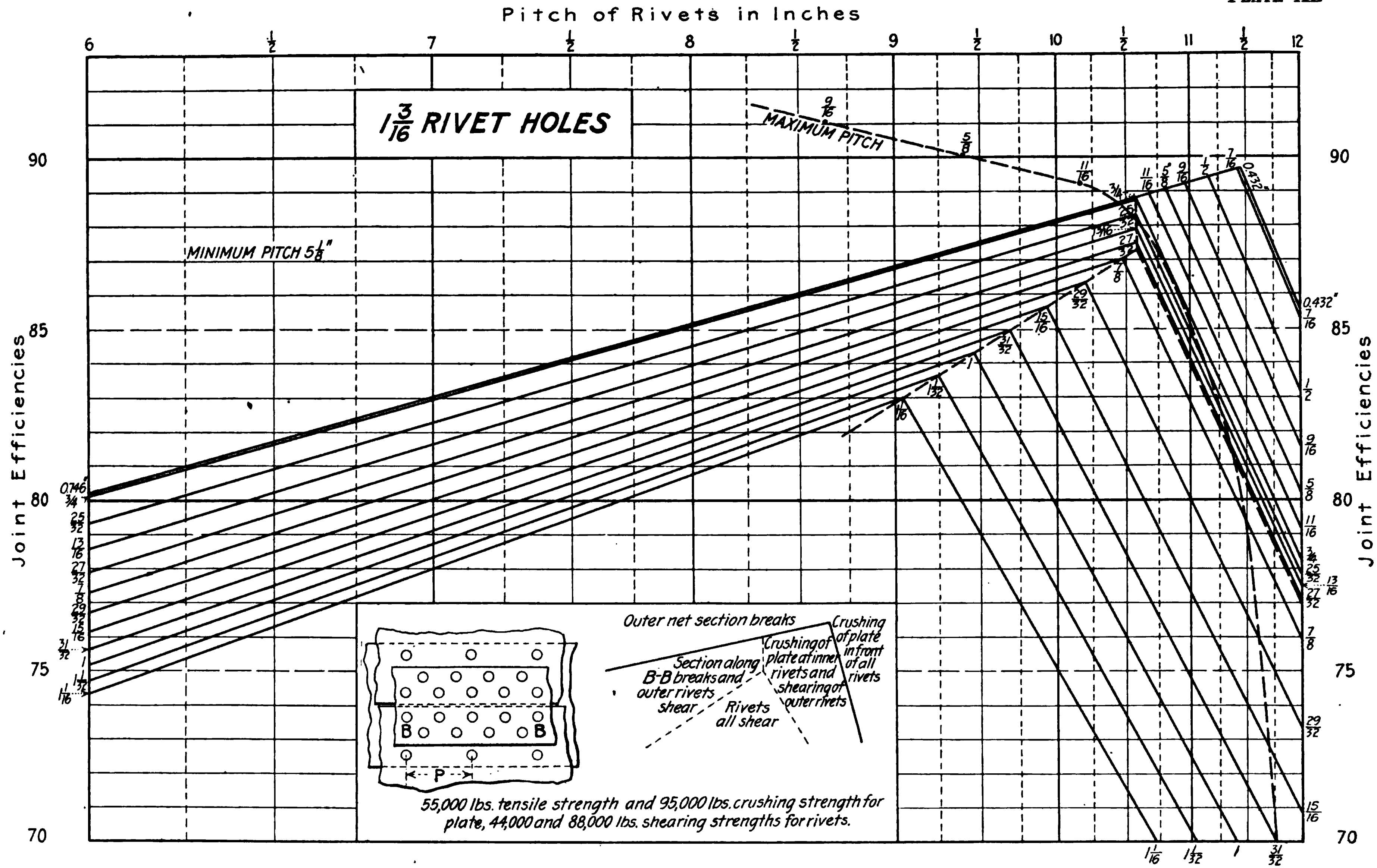
Pitch of Rivets in Inches
6
1/2
7
1/2
8
1/2
9
1/2
10
1/2
11
1/2
12
7/8 RIVET HOLES
Joint Efficiencies
90
85
80
75
70
MAXIMUM PITCH
MINIMUM PITCH 3 15/16"
13/32
7/16
1/2
0.550
9/16
19/32
5/8
21/32
11/16
23/32
3/4
3/8
0.318"
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.


Pitch of Rivets in Inches
15/16 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 4 1/8"
Joint Efficiencies
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.

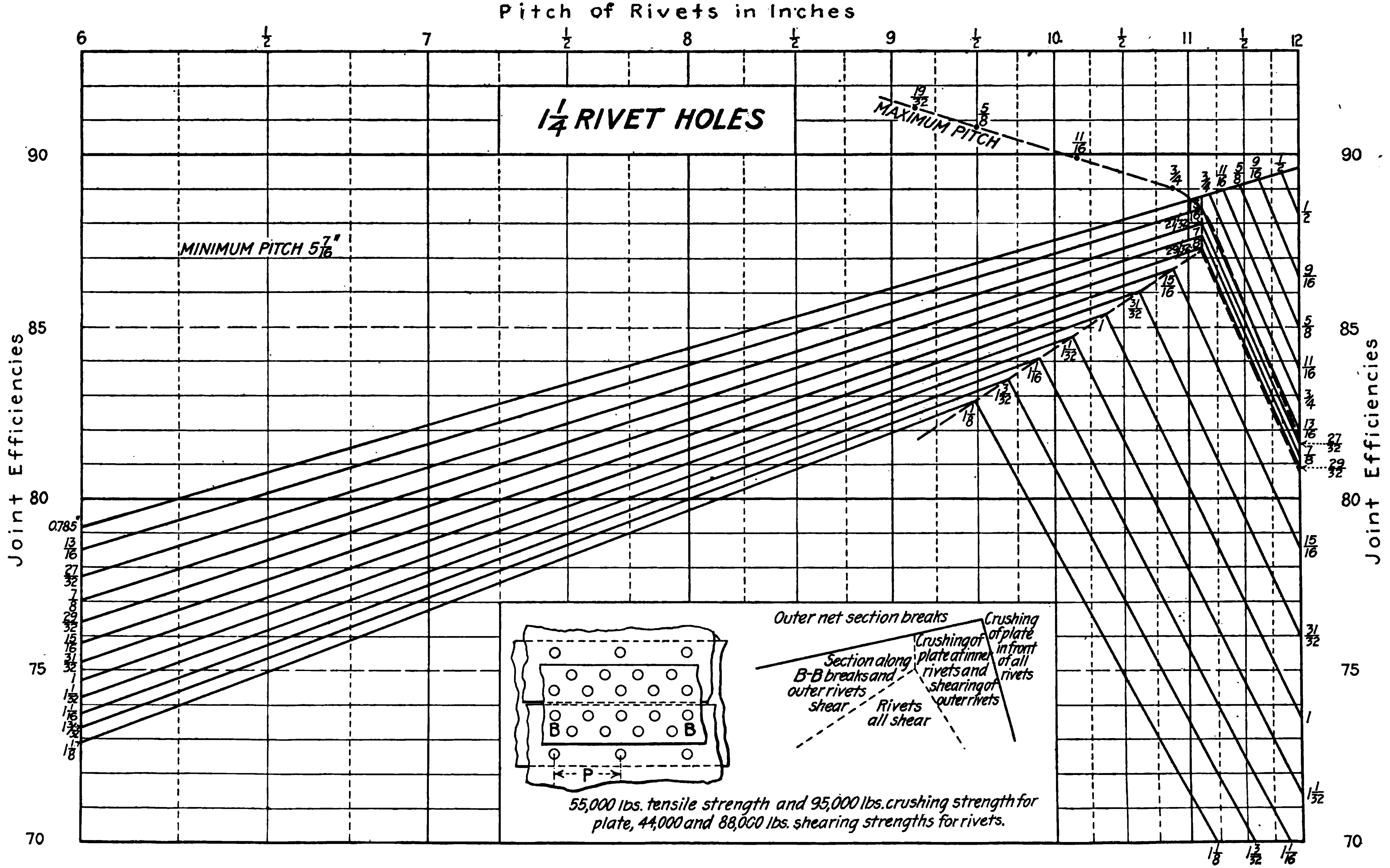

Pitch of Rivets in Inches
Joint Efficiencies
I. RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 4½"
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.

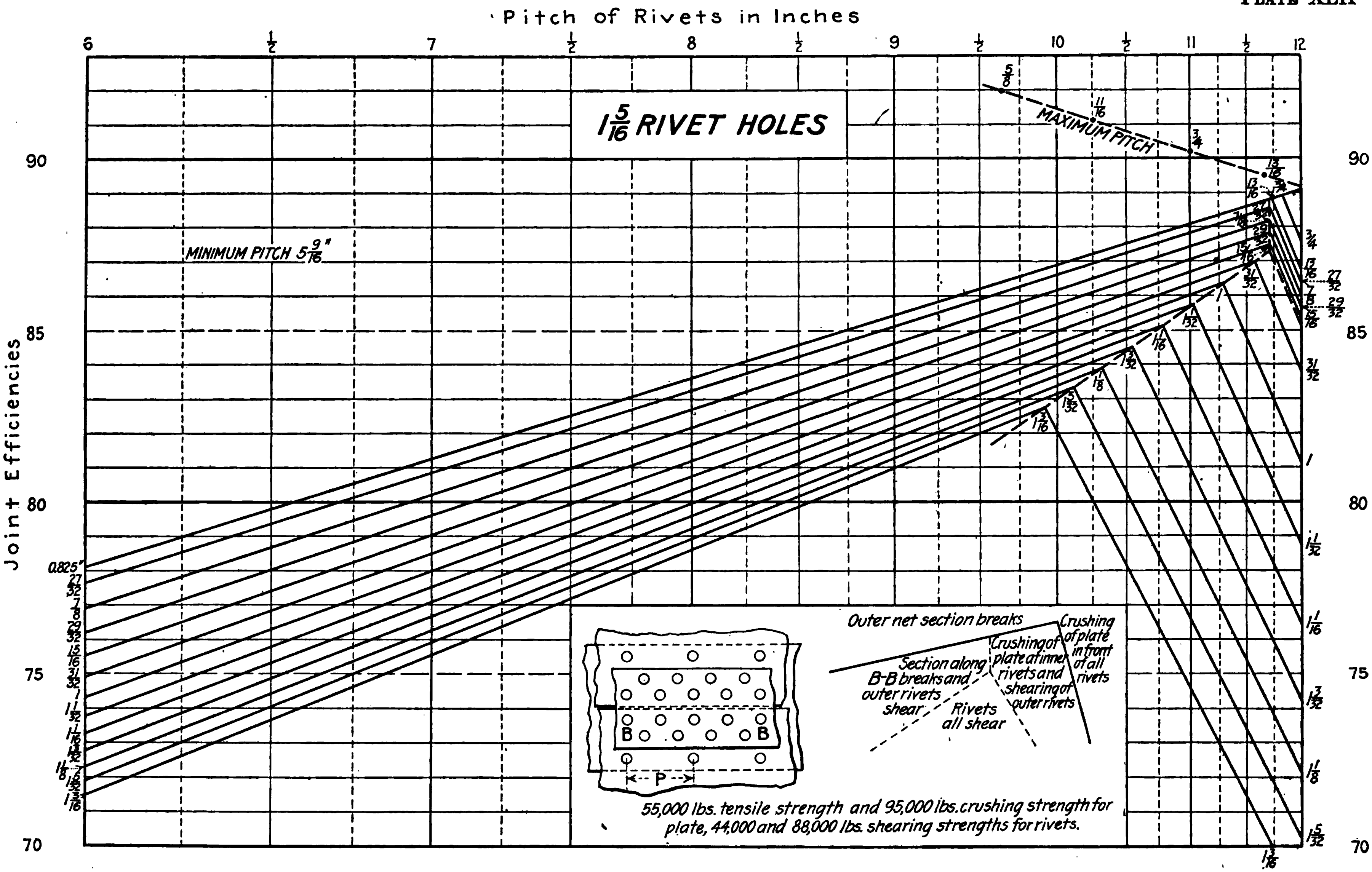

Pitch of Rivets in Inches
1 1/16 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 4 3/4"
Joint Efficiencies
Outer net section breaks
Section along B-B breaks and outer rivets shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
Rivets all shear
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.

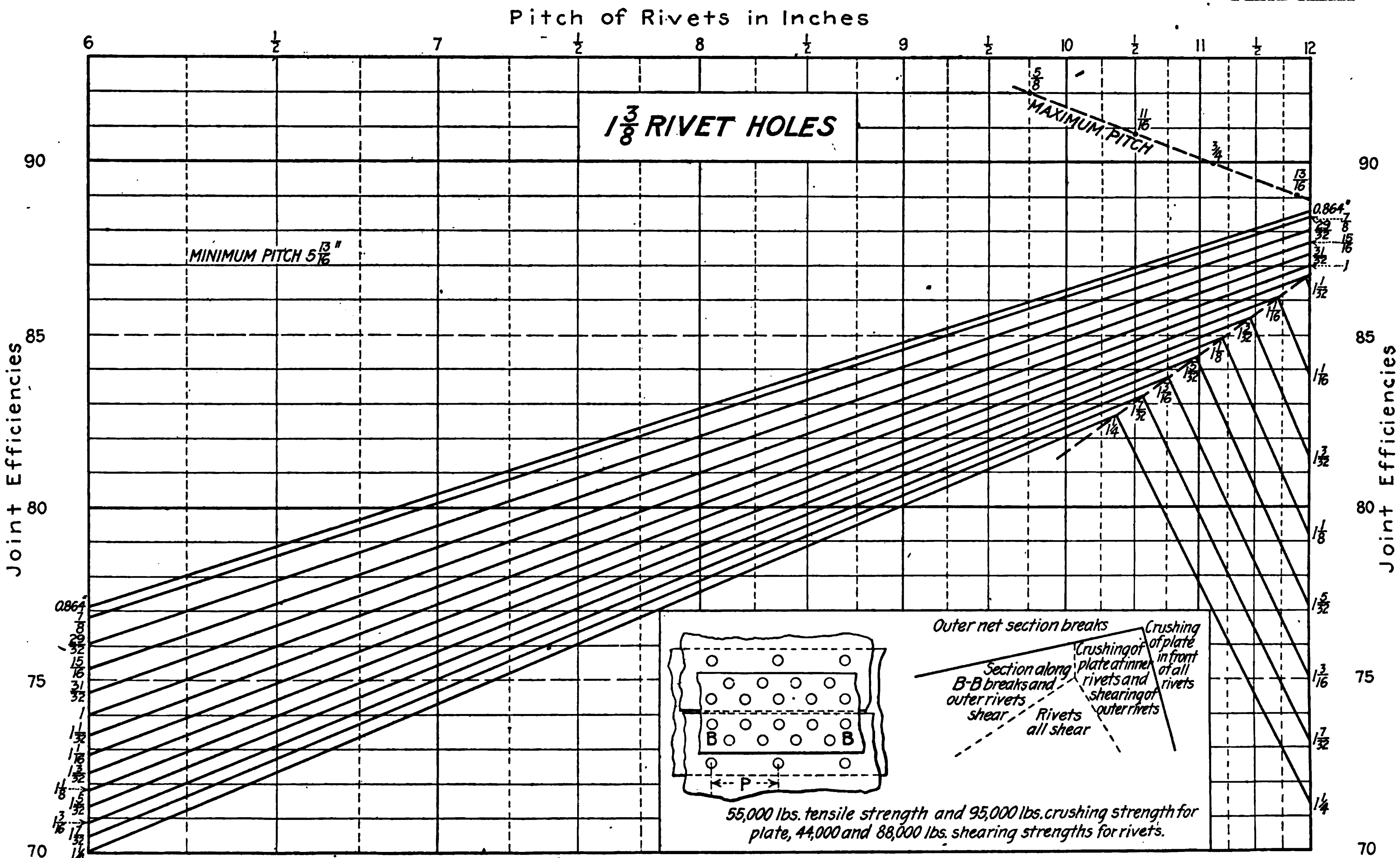

Pitch of Rivets in Inches
6
1/2
1/2
8
1/2
9
1/2
10
1/2
11
1/2
12
1 1/8 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 4 15/16"
Joint Efficiencies
90
85
80
75
70
0.409"
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.

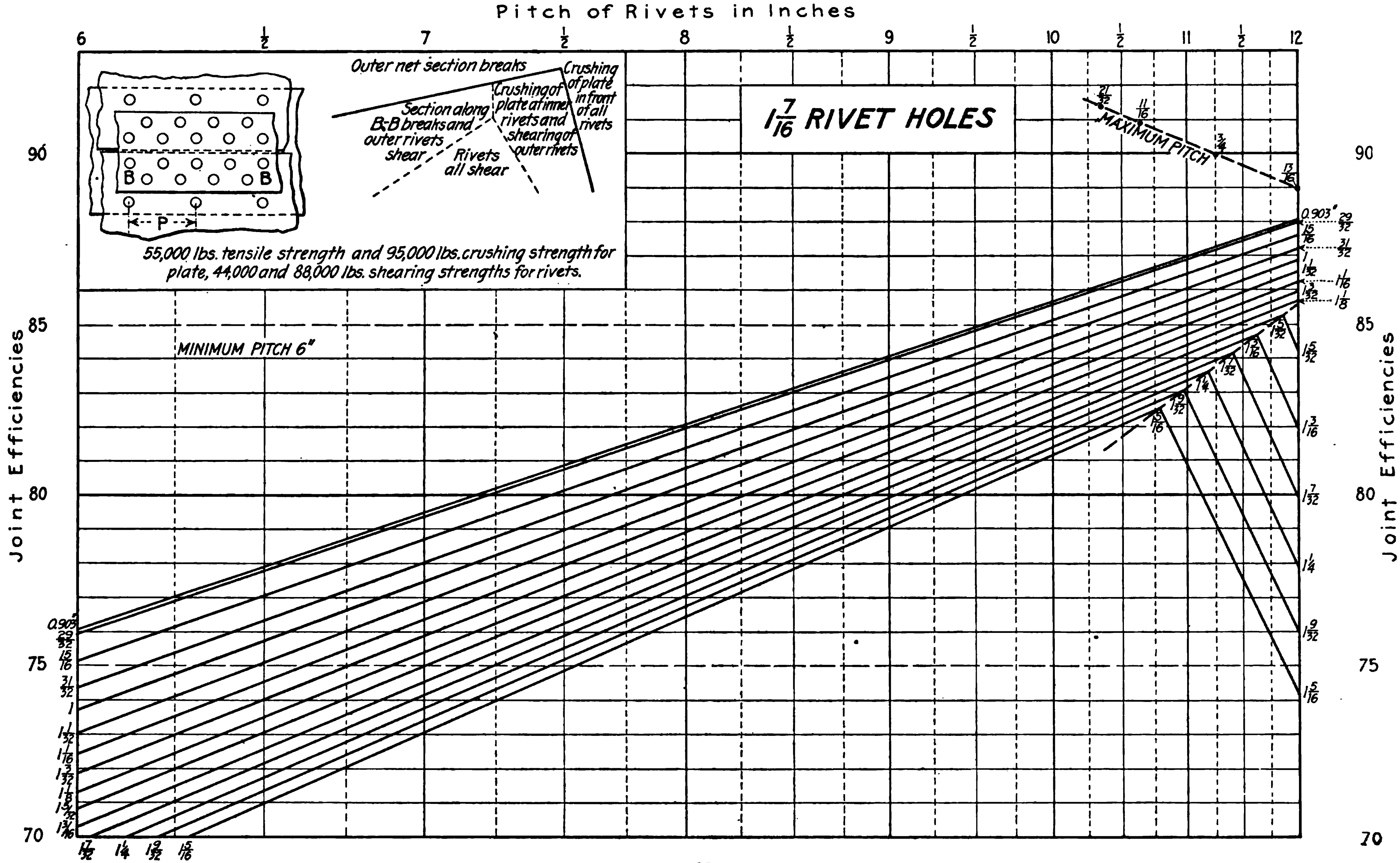


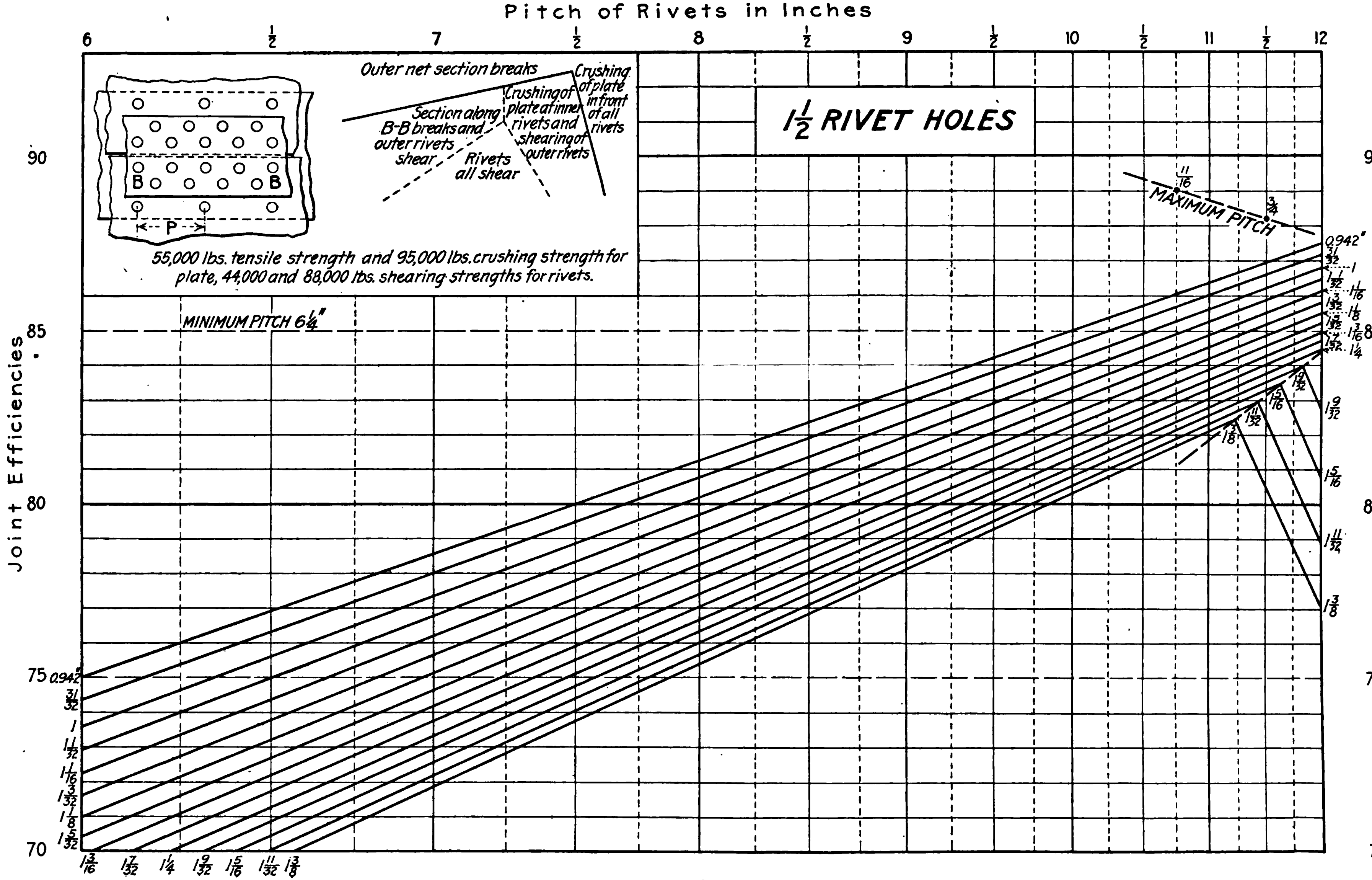
Pitch of Rivets in Inches
Joint Efficiencies
1 3/16 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 5 1/8"
Outer net section breaks
Crushing of plate in front of all rivets
Crushing of plate at inner rivets and shearing of outer rivets
Section along B-B breaks and outer rivets shear
Rivets all shear
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.


Pitch of Rivets in Inches
Joint Efficiencies
$1\frac{1}{4}$ RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH $5\frac{7}{16}''$
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.

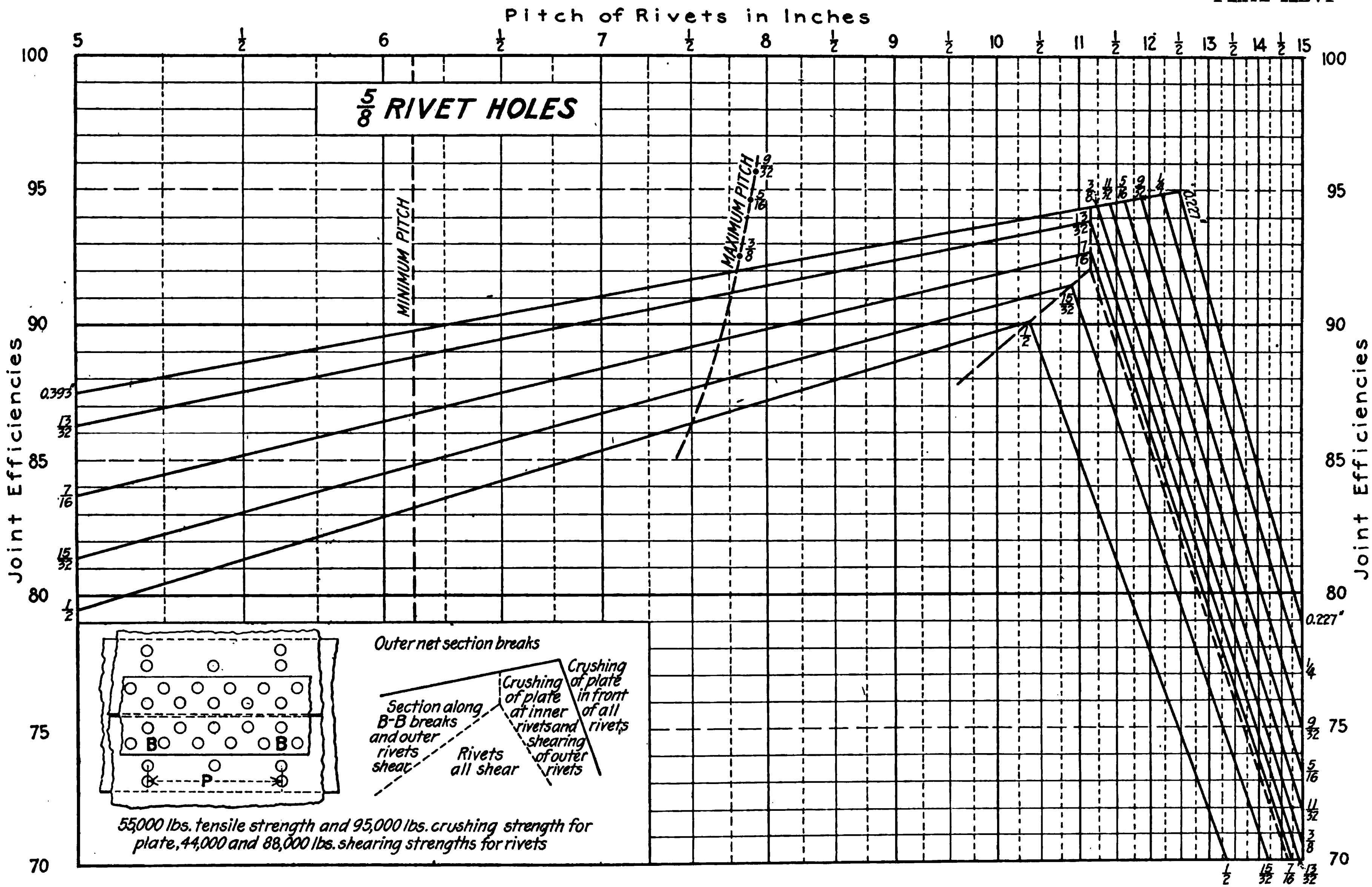

Pitch of Rivets in Inches
Joint Efficiencies
$1\frac{5}{16}$ RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH $5\frac{9}{16}$"
Outer net section breaks
Crushing of plate in front of all rivets
Crushing of plate at inner rivets and shearing of outer rivets
Section along B-B breaks and outer rivets shear
Rivets all shear
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.

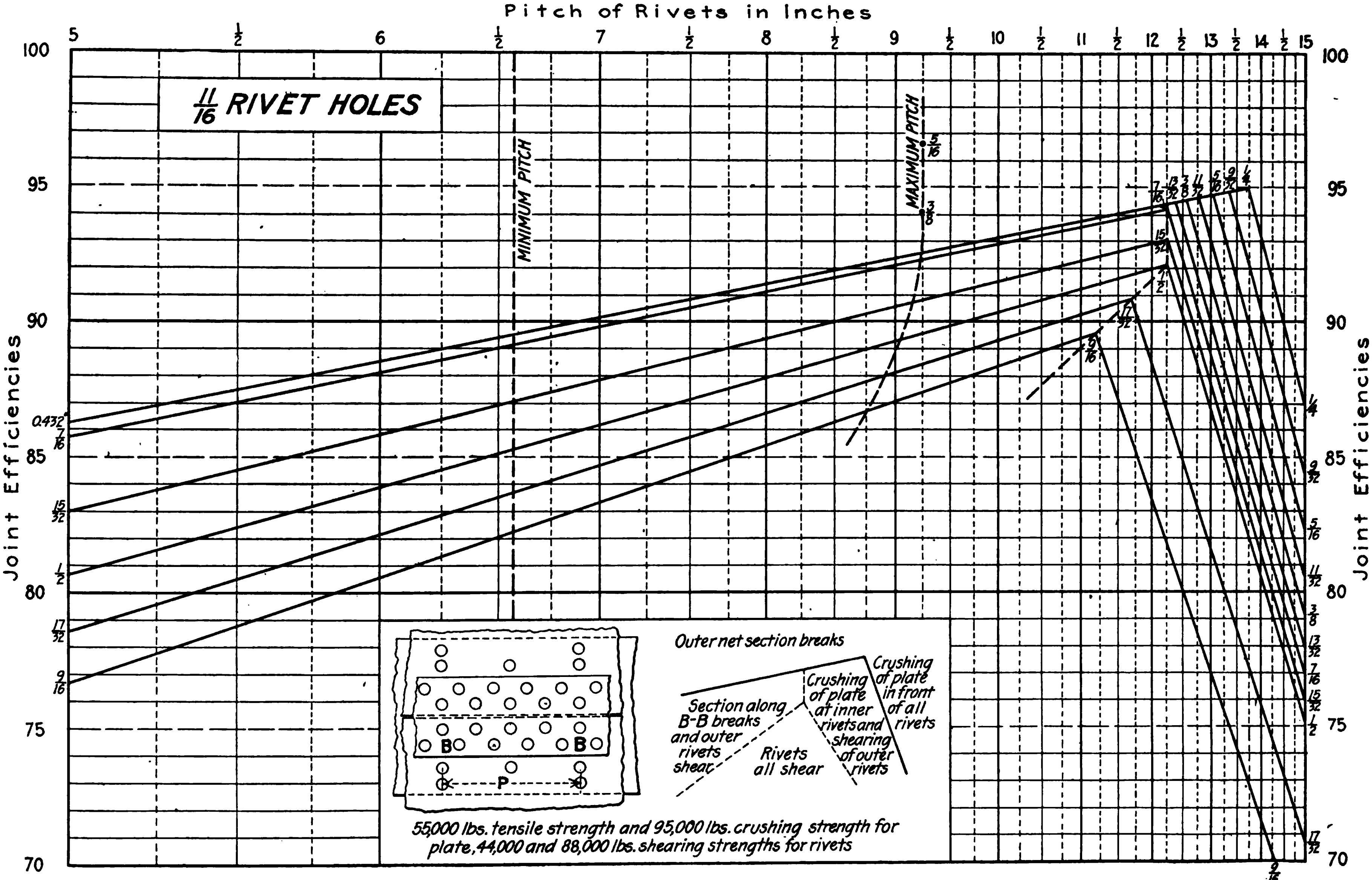

Pitch of Rivets in Inches
Joint Efficiencies
1 3/8 RIVET HOLES
MINIMUM PITCH 5 13/16"
MAXIMUM PITCH
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.

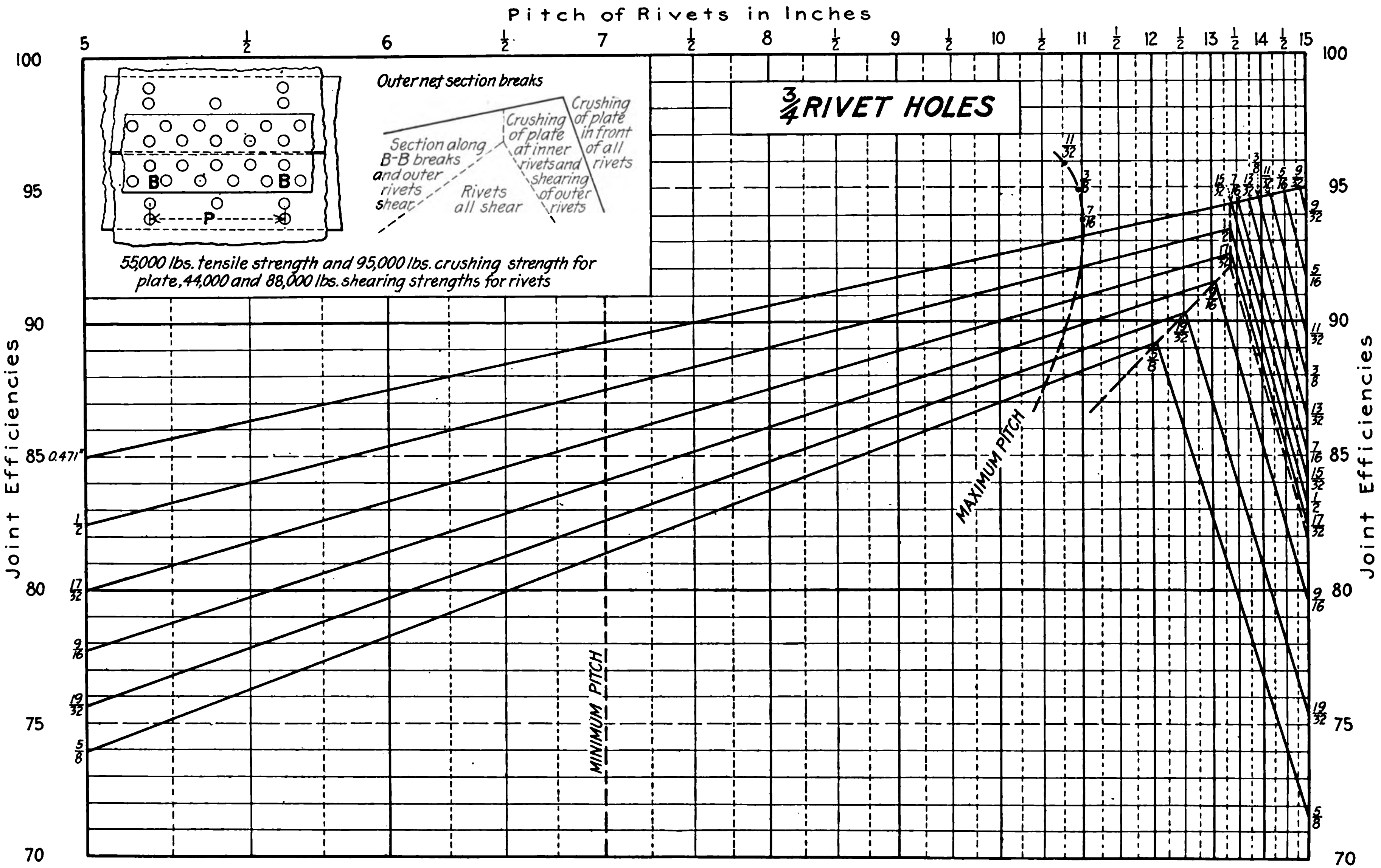

Pitch of Rivets in Inches
Joint Efficiencies
1 7/16 RIVET HOLES
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.
MINIMUM PITCH 6"
MAXIMUM PITCH

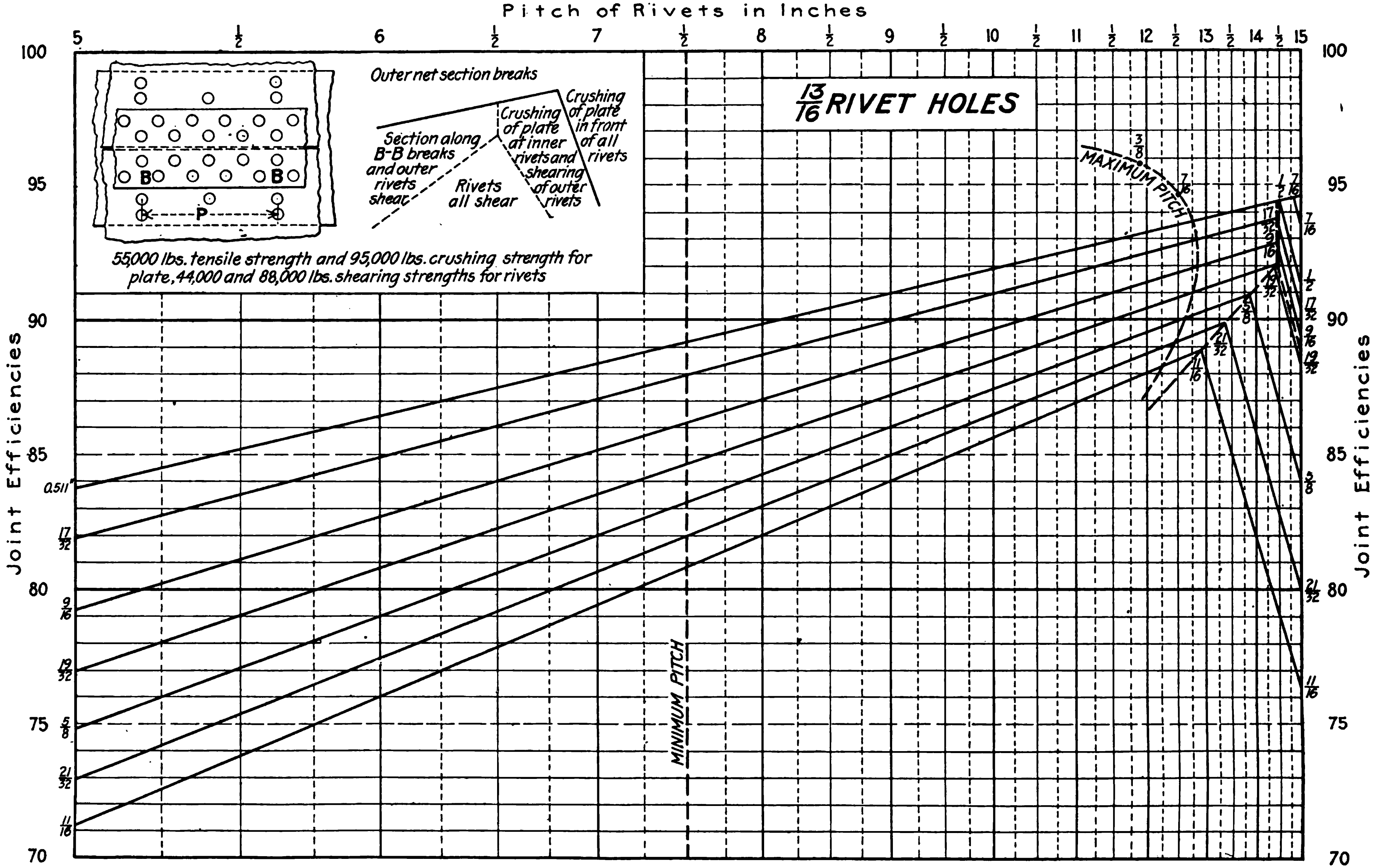


Pitch of Rivets in Inches
6
½
7
½
8
½
9
½
10
½
11
½
12
Joint Efficiencies
90
85
80
75
70
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
P
B
B
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets.
1½ RIVET HOLES
MINIMUM PITCH 6¼"
MAXIMUM PITCH
11/16
¾
0.942"
31/32
1
1 1/32
1 1/16
1 3/32
1 1/8
1 5/32
1 3/16
1 7/32
1 1/4
1 9/32
1 5/16
1 11/32
1 3/8

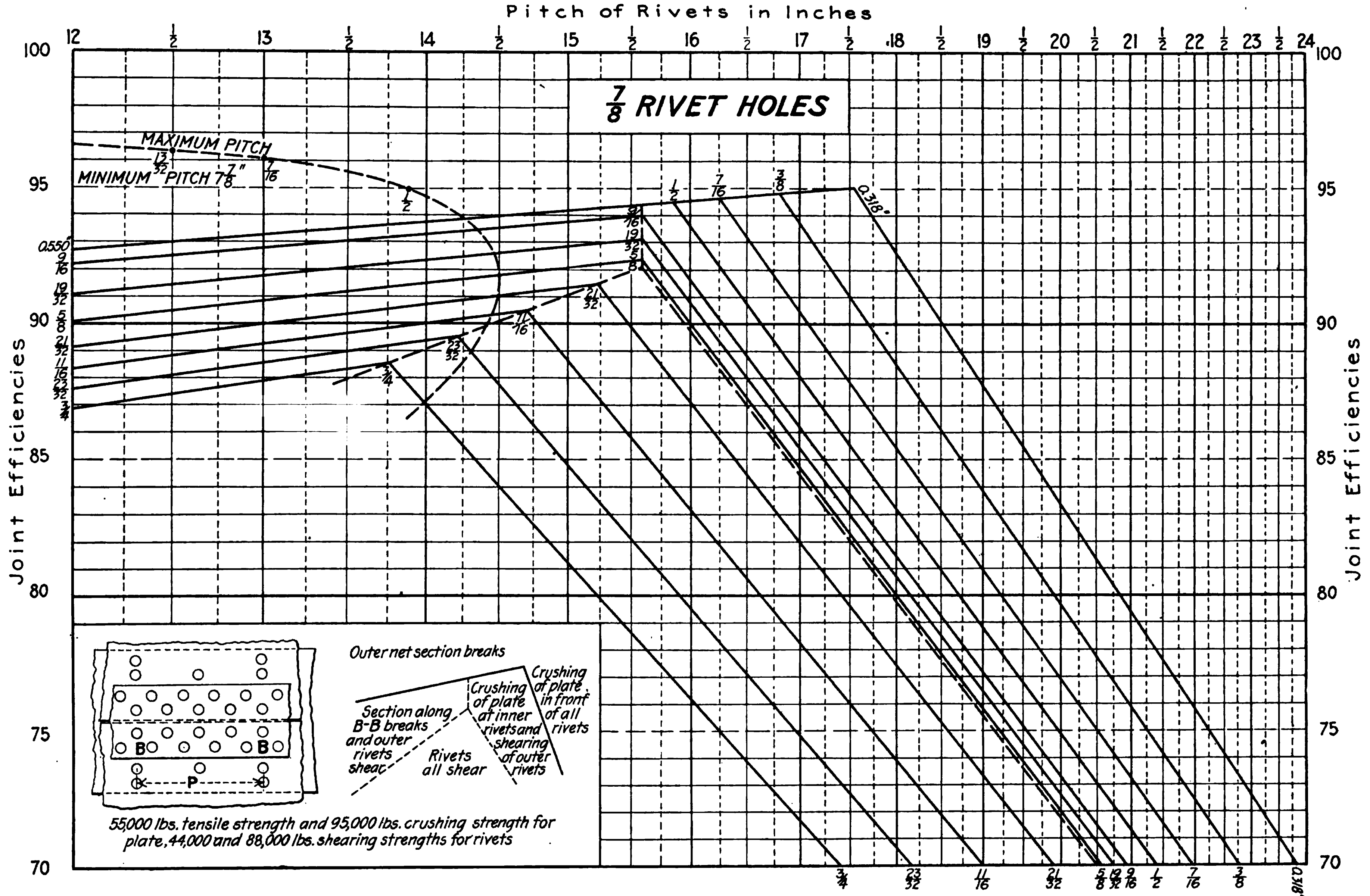

Pitch of Rivets in Inches
Joint Efficiencies
5/8 RIVET HOLES
MINIMUM PITCH
MAXIMUM PITCH
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets

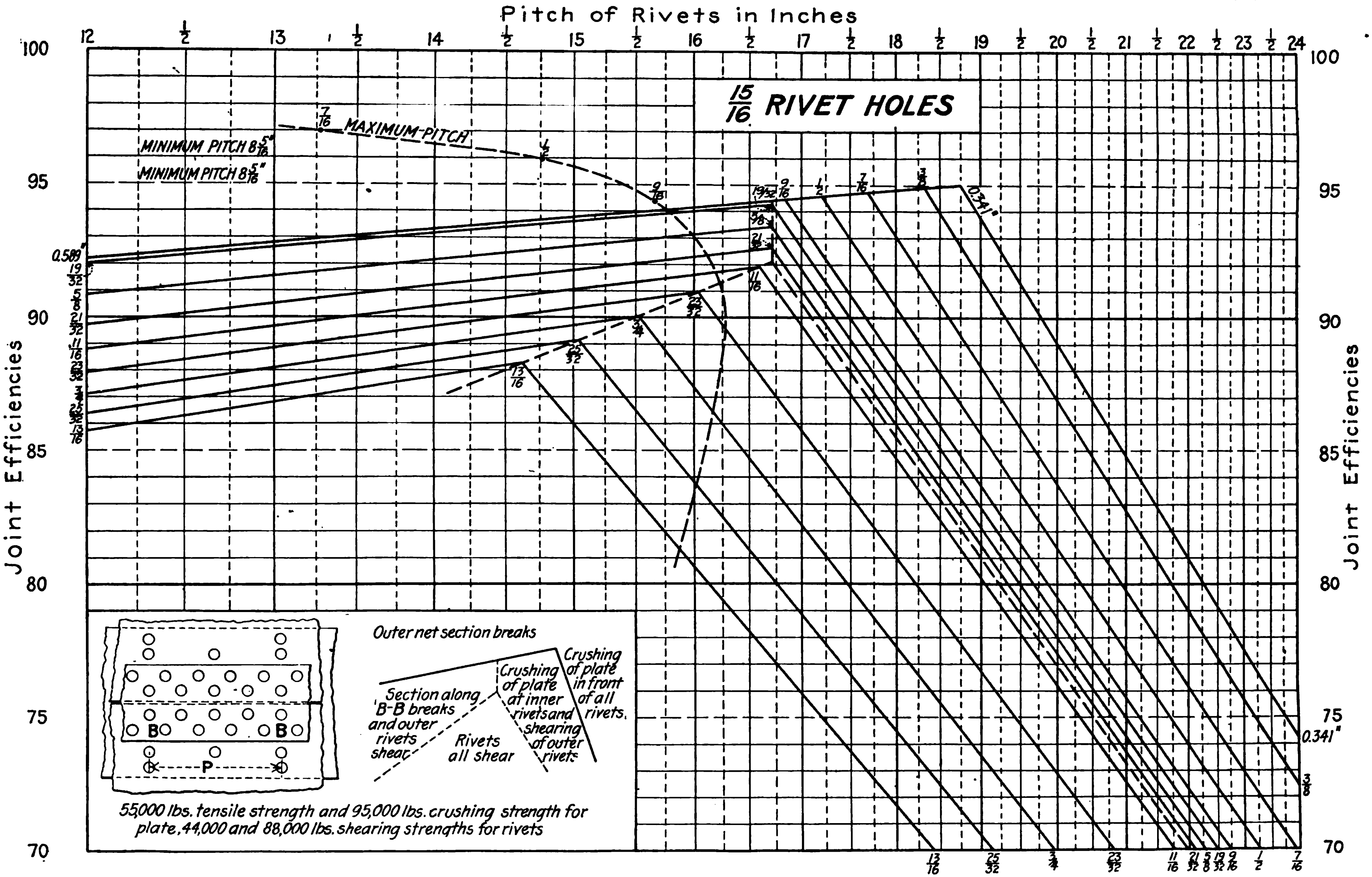

Pitch of Rivets in Inches
11/16 RIVET HOLES
MINIMUM PITCH
MAXIMUM PITCH
Joint Efficiencies
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets

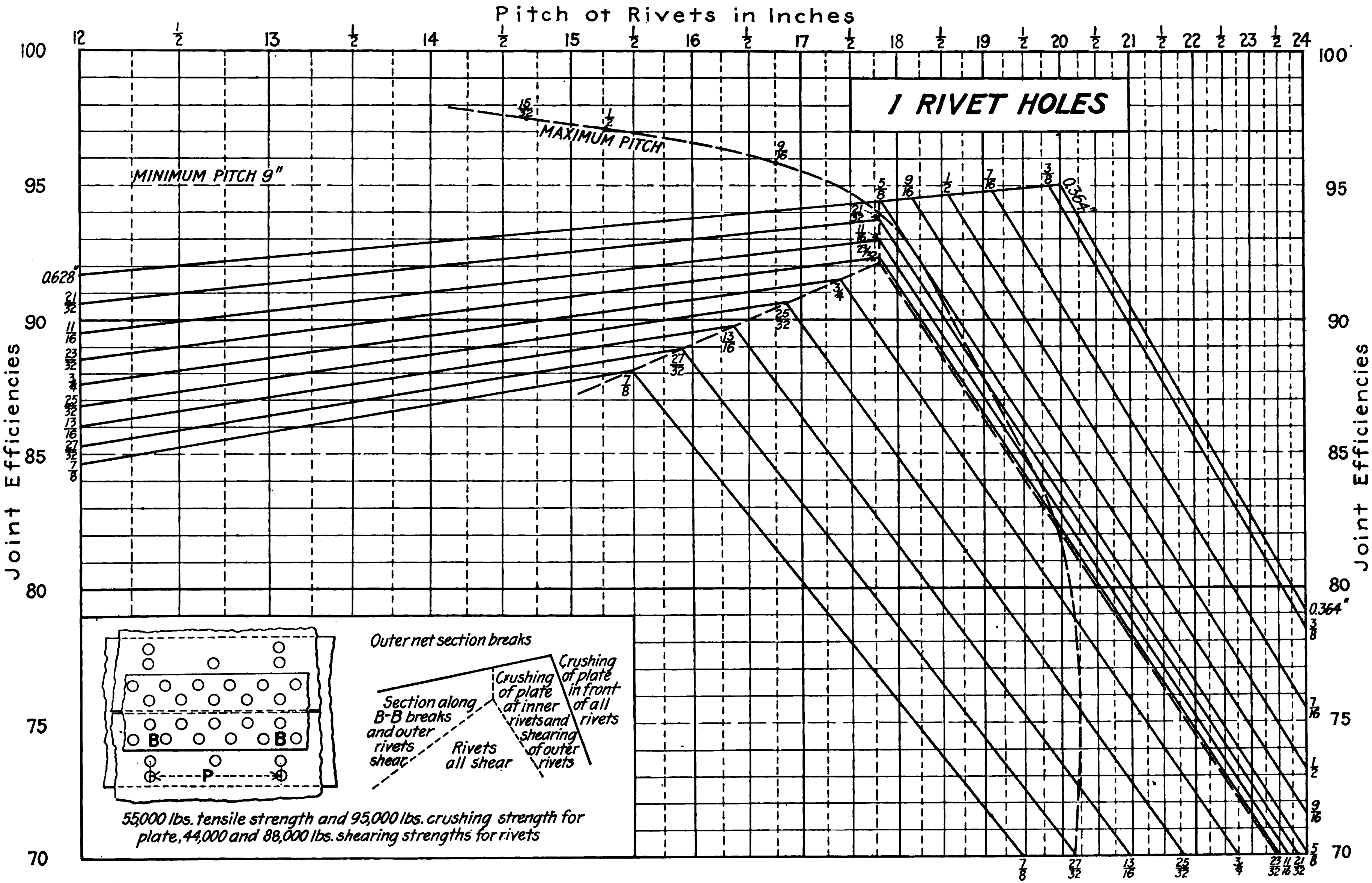

Pitch of Rivets in Inches
5
1/2
6
1/2
7
1/2
8
1/2
9
1/2
10
1/2
11
1/2
12
1/2
13
1/2
14
1/2
15
100
95
90
85
80
75
70
Joint Efficiencies
3/4 RIVET HOLES
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets
0.471"
MINIMUM PITCH
MAXIMUM PITCH

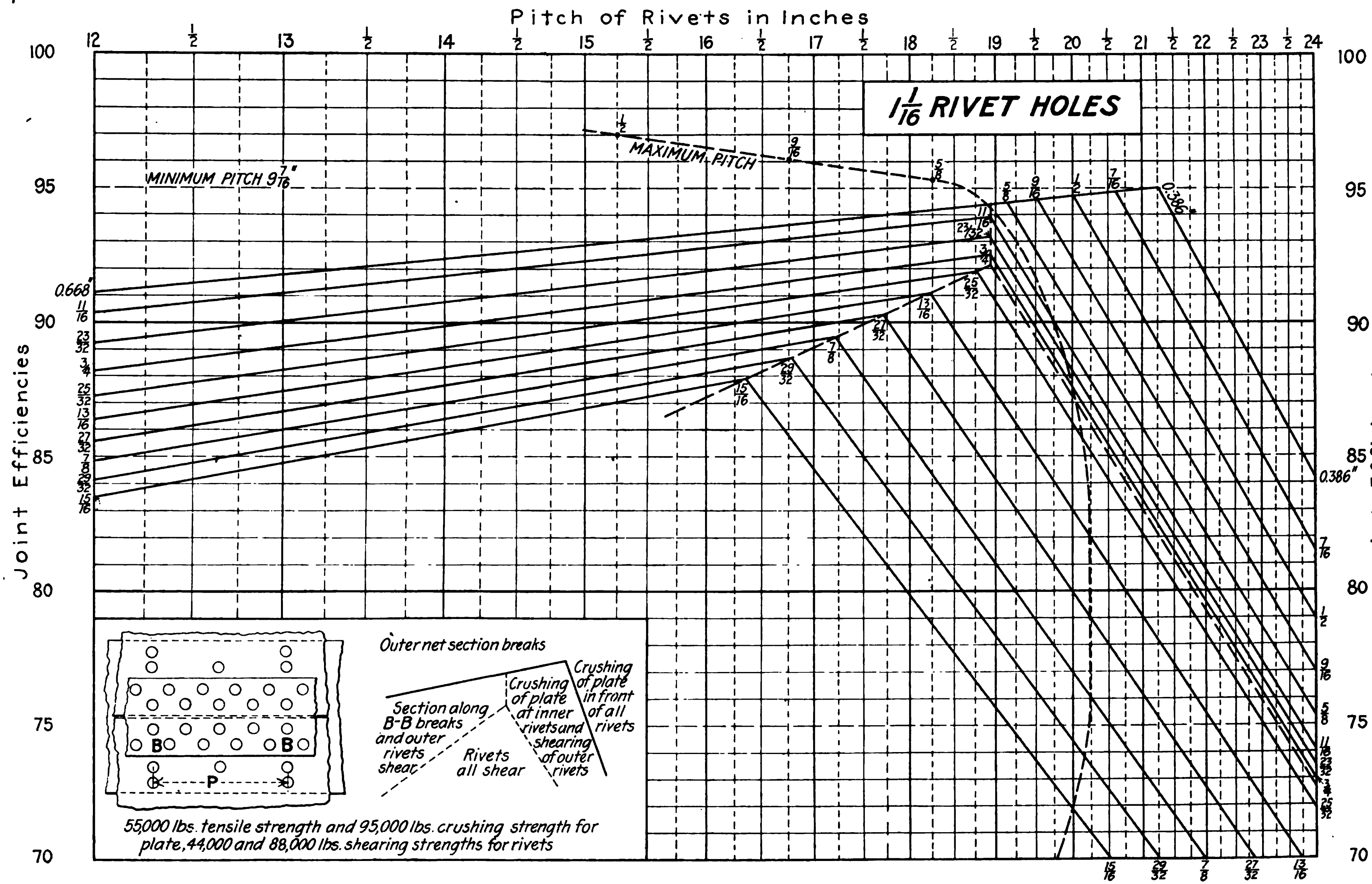


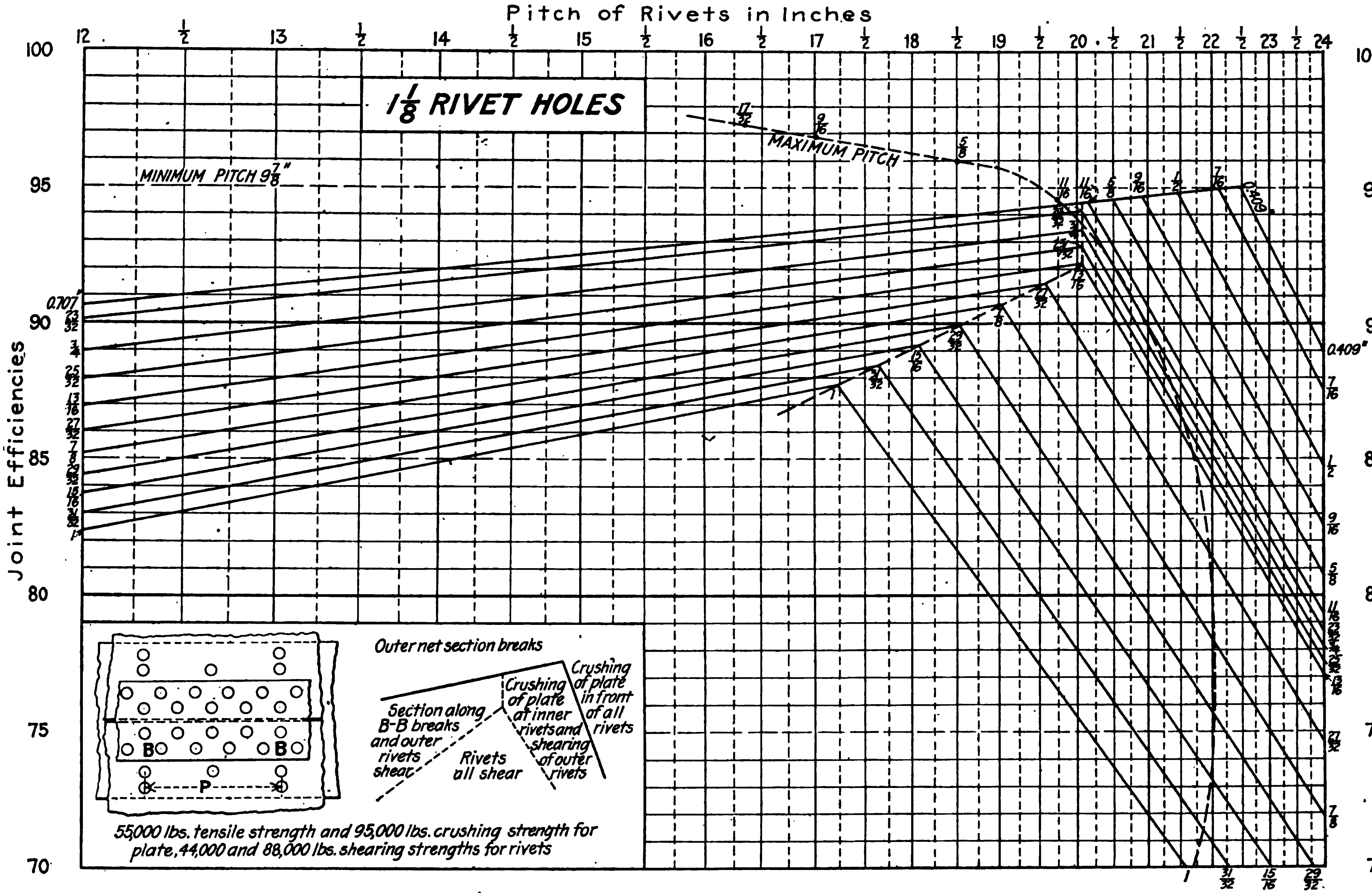
Pitch of Rivets in Inches
5
½
6
½
7
½
8
½
9
½
10
½
11
½
12
½
13
½
14
½
15
Joint Efficiencies
100
95
90
85
80
75
70
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets
13/16 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH
0.511"
17/32
9/16
19/32
5/8
21/32
11/16
3/8
7/16
1/2

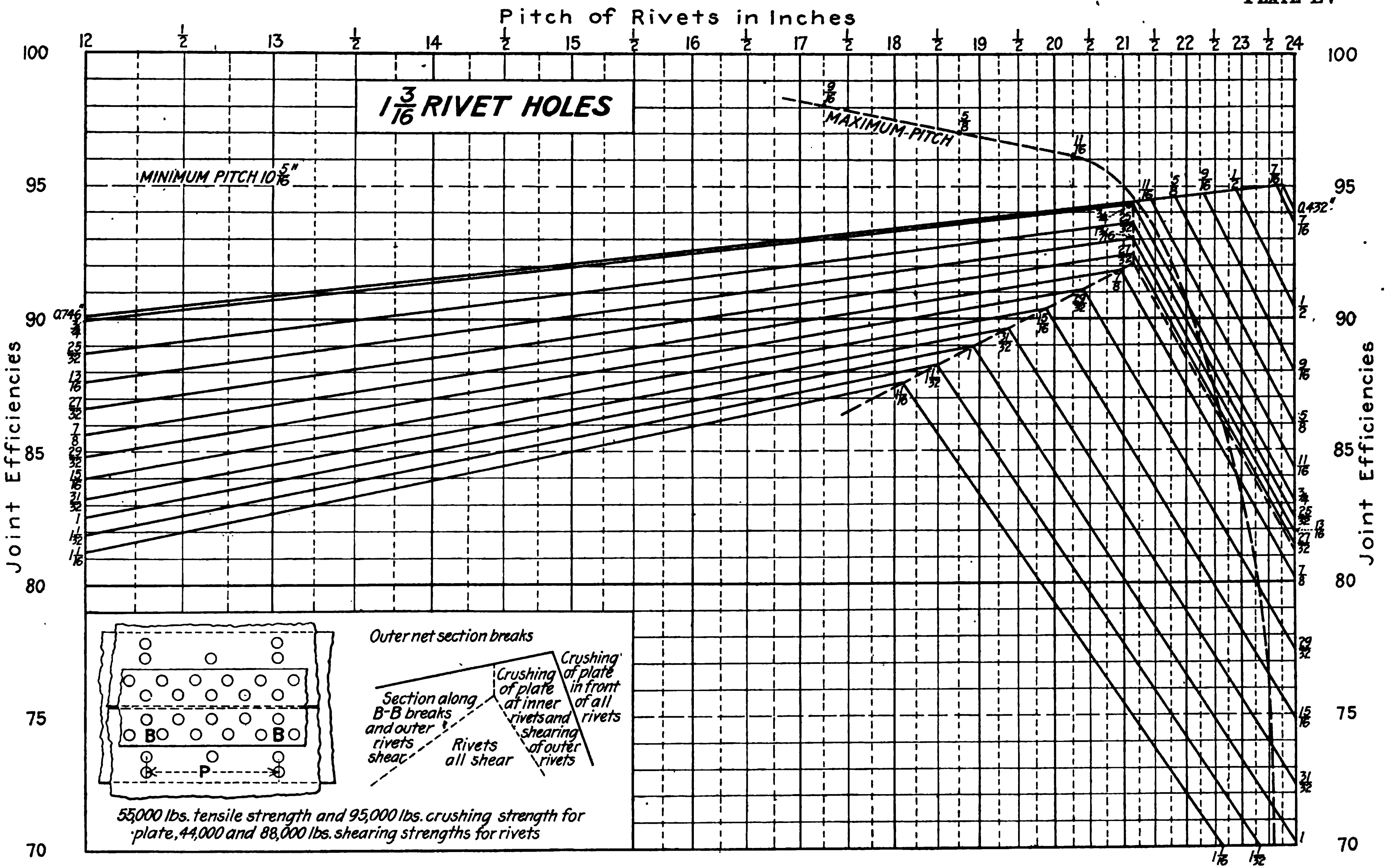

Pitch of Rivets in Inches
Joint Efficiencies
7/8 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 7 7/8"
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets

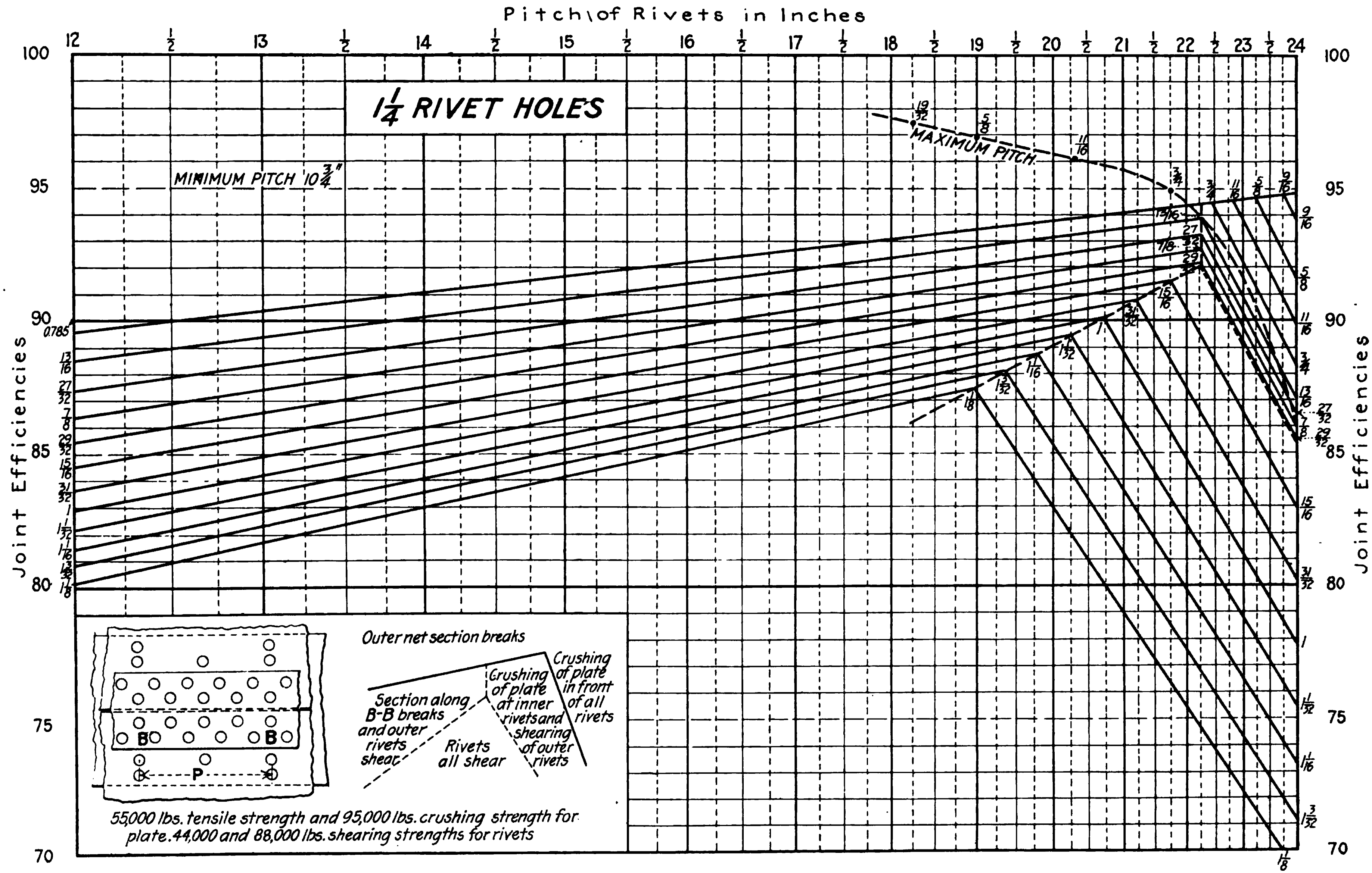

Pitch of Rivets in Inches
15/16 RIVET HOLES
Joint Efficiencies
MAXIMUM PITCH
MINIMUM PITCH 8 5/16"
MINIMUM PITCH 8 5/16"
0.589"
0.341"
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets.
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets

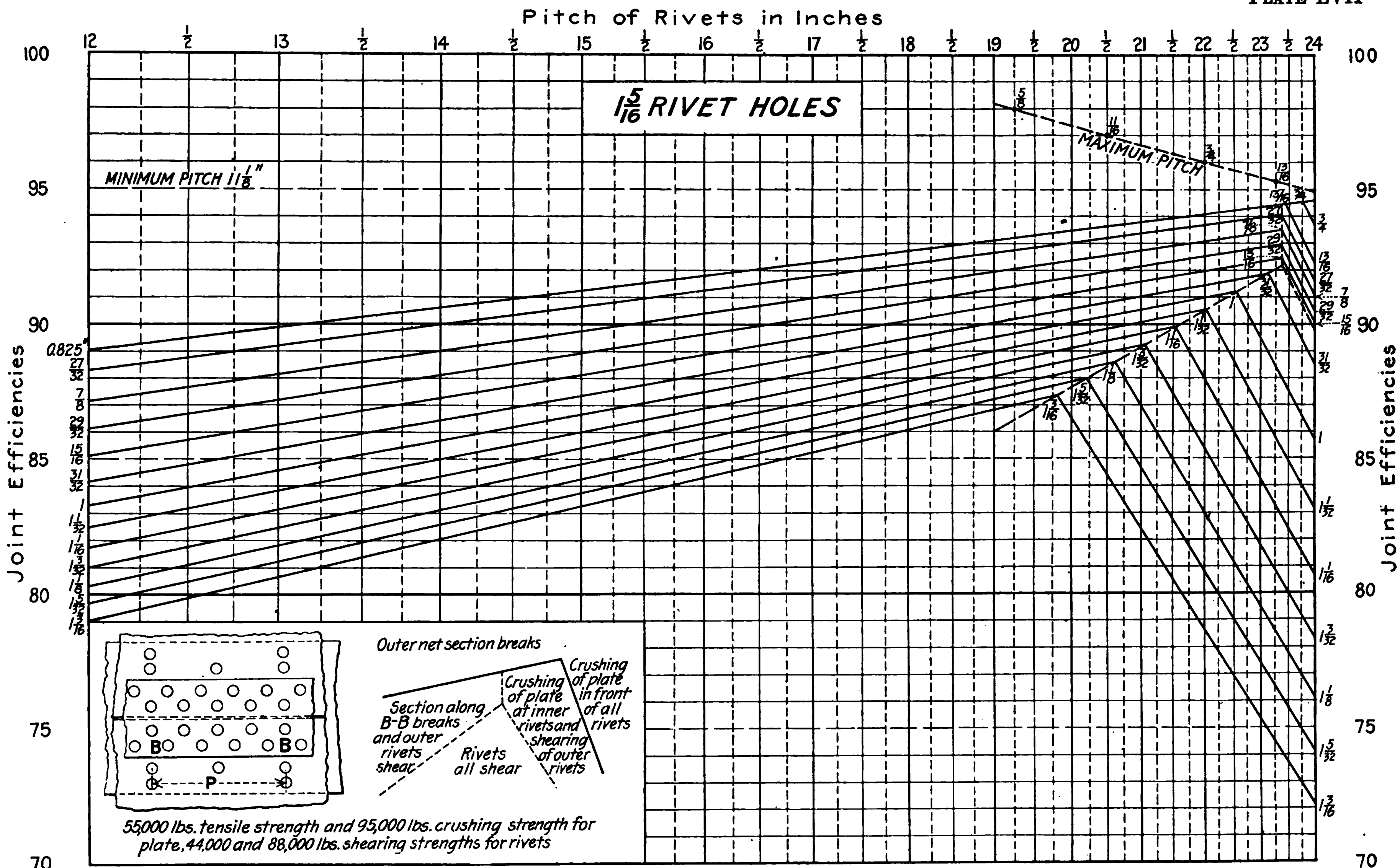

Pitch of Rivets in Inches
1 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 9"
Joint Efficiencies
0.628"
0.364"
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets

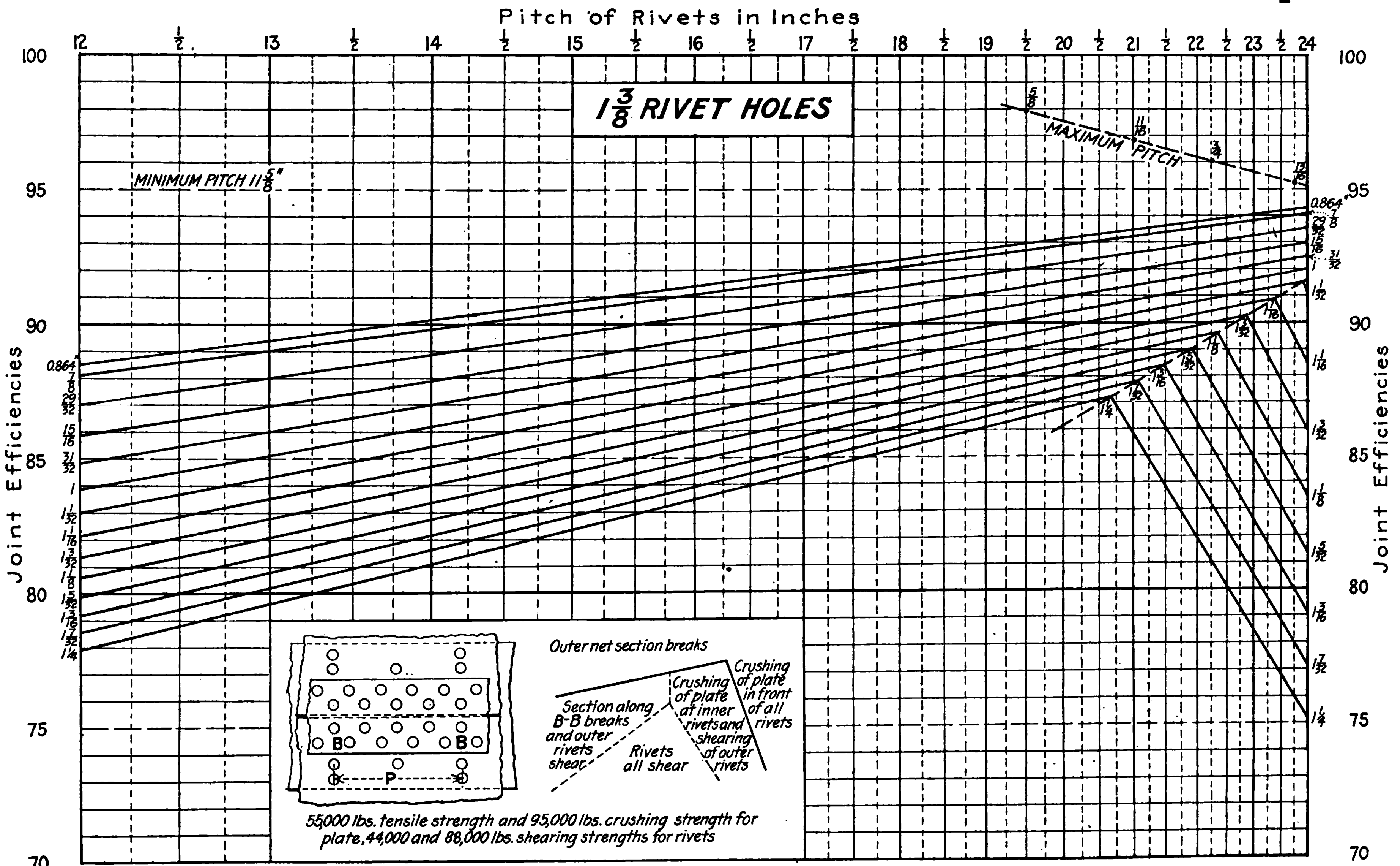

Pitch of Rivets in Inches
$1\frac{1}{16}$ RIVET HOLES
MINIMUM PITCH $9\frac{7}{16}$"
MAXIMUM PITCH
Joint Efficiencies
0.668"
0.386"
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets

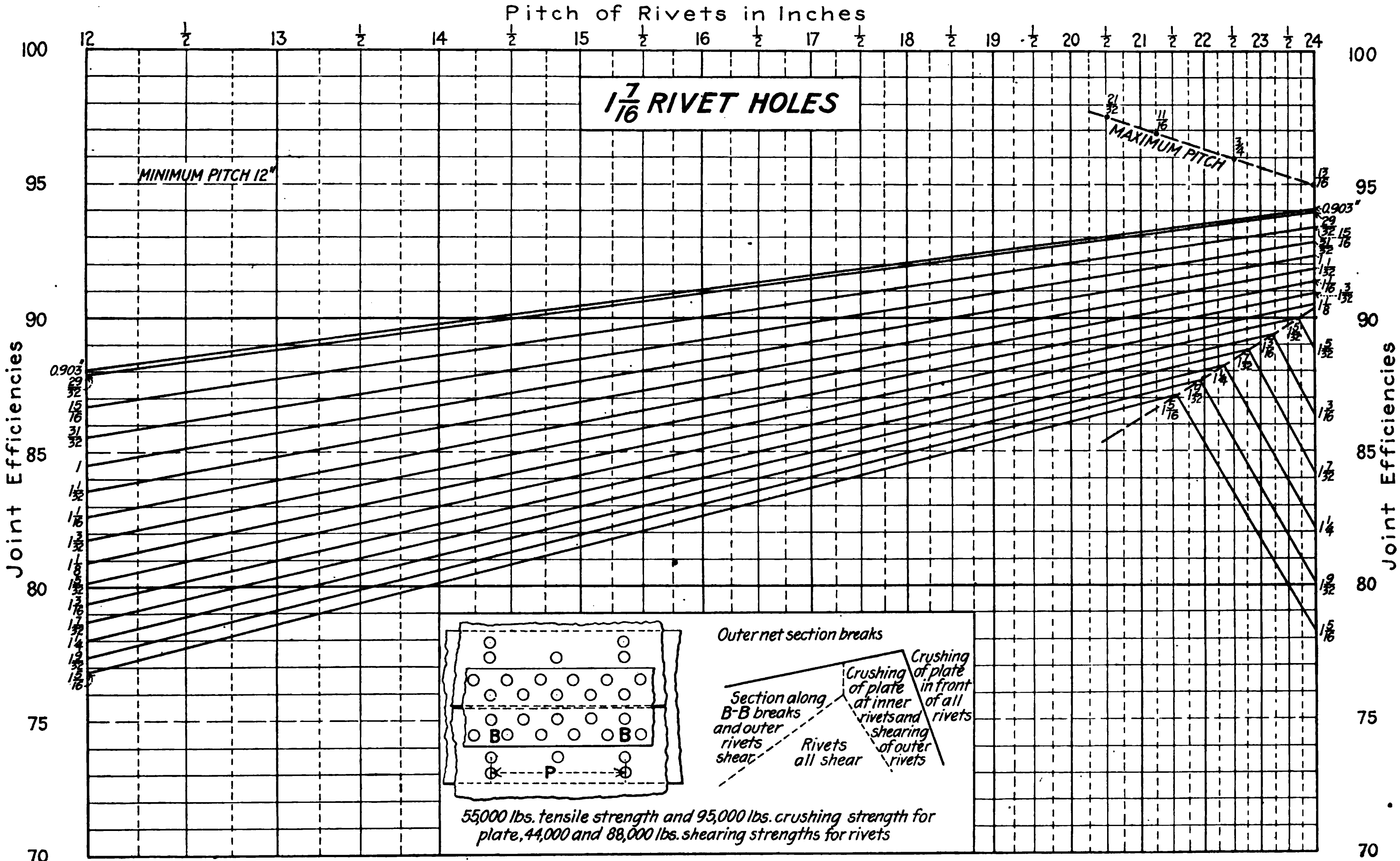

Pitch of Rivets in Inches
1 1/8 RIVET HOLES
MINIMUM PITCH 9 7/8"
MAXIMUM PITCH
Joint Efficiencies
0.707"
0.409"
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
B
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets

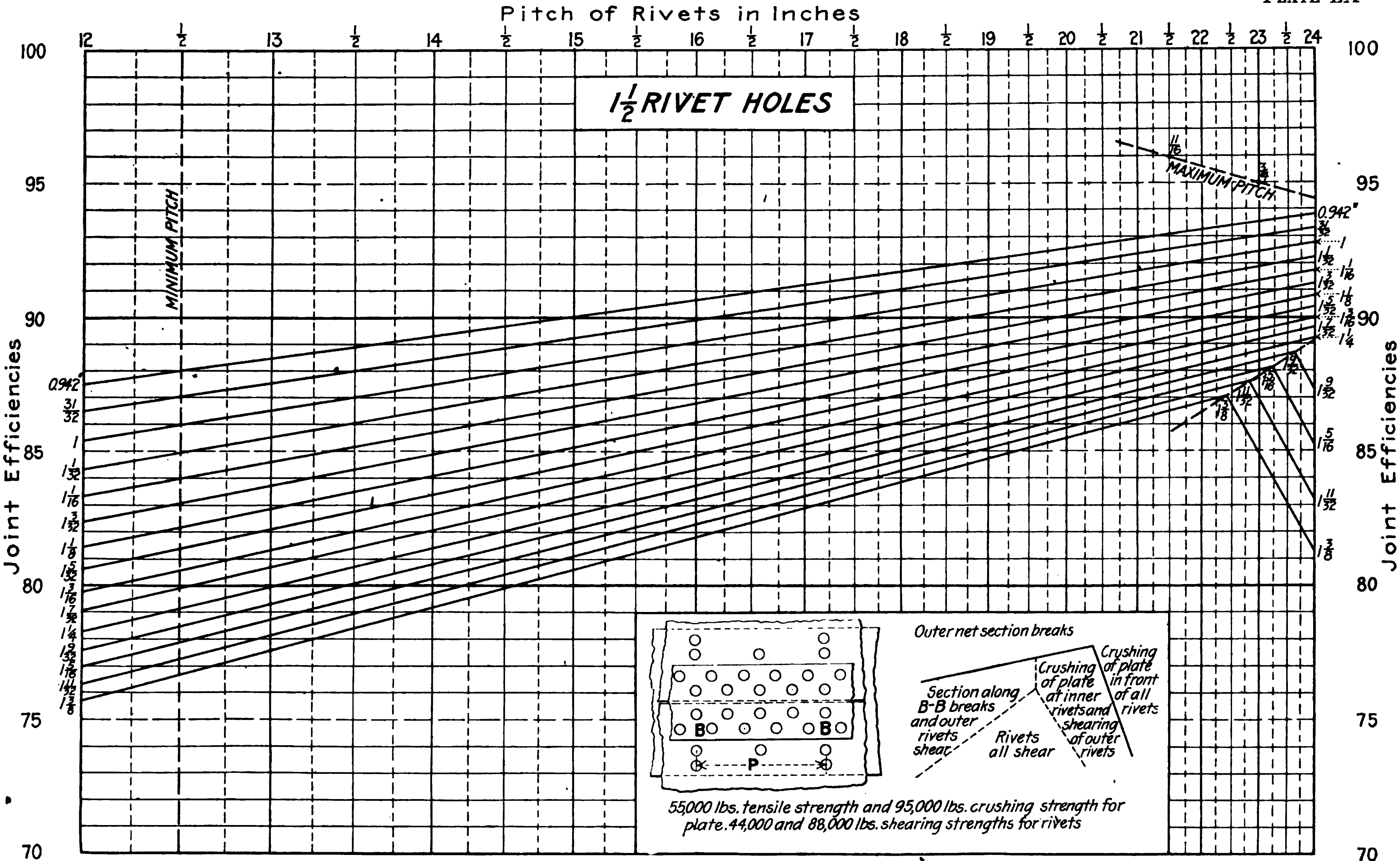

Pitch of Rivets in Inches
$1\frac{3}{16}$ RIVET HOLES
MINIMUM PITCH $10\frac{5}{16}$"
MAXIMUM-PITCH
Joint Efficiencies
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets

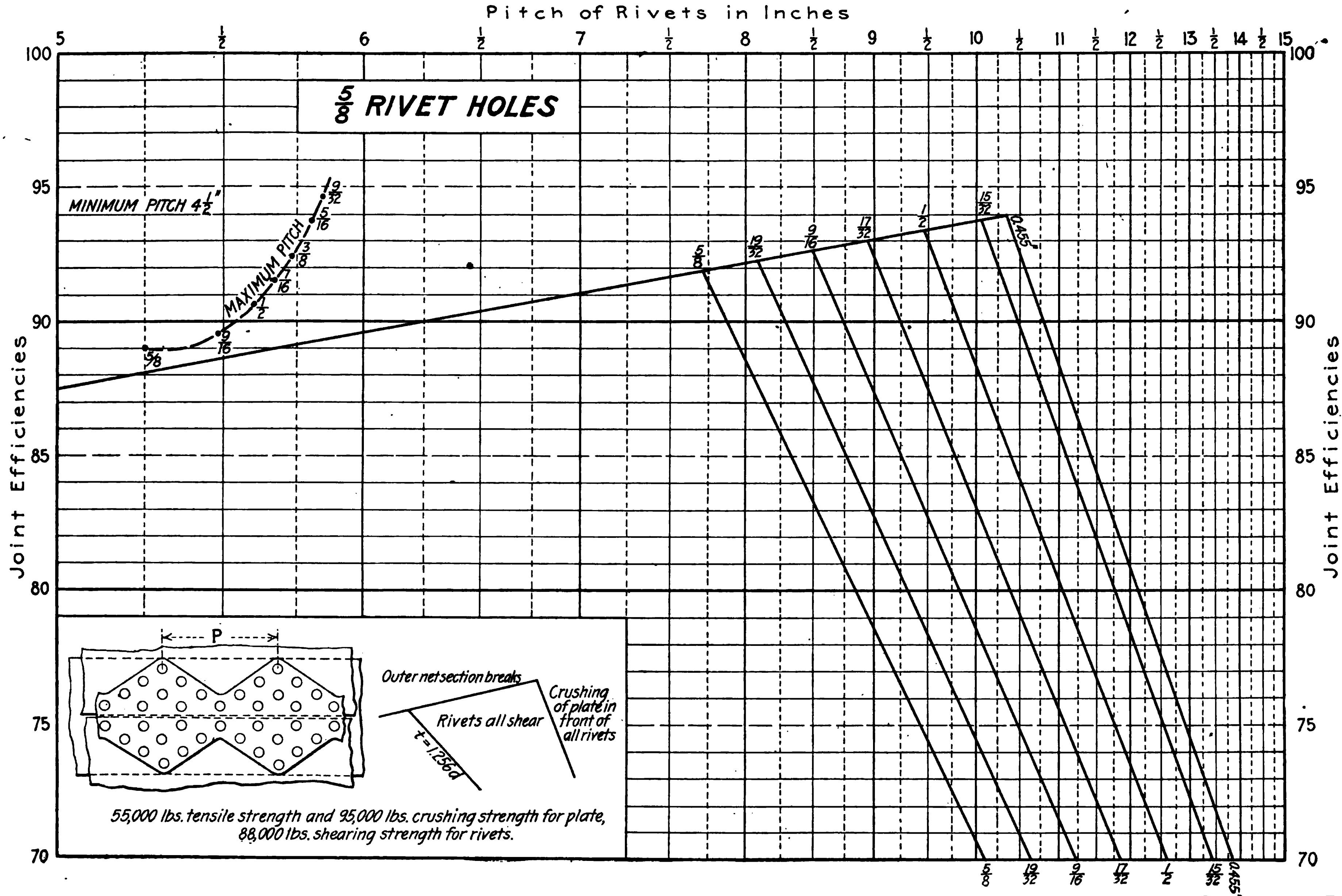

Pitch of Rivets in Inches
1 1/4 RIVET HOLES
MINIMUM PITCH 10 3/4"
MAXIMUM PITCH
Joint Efficiencies
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate. 44,000 and 88,000 lbs. shearing strengths for rivets

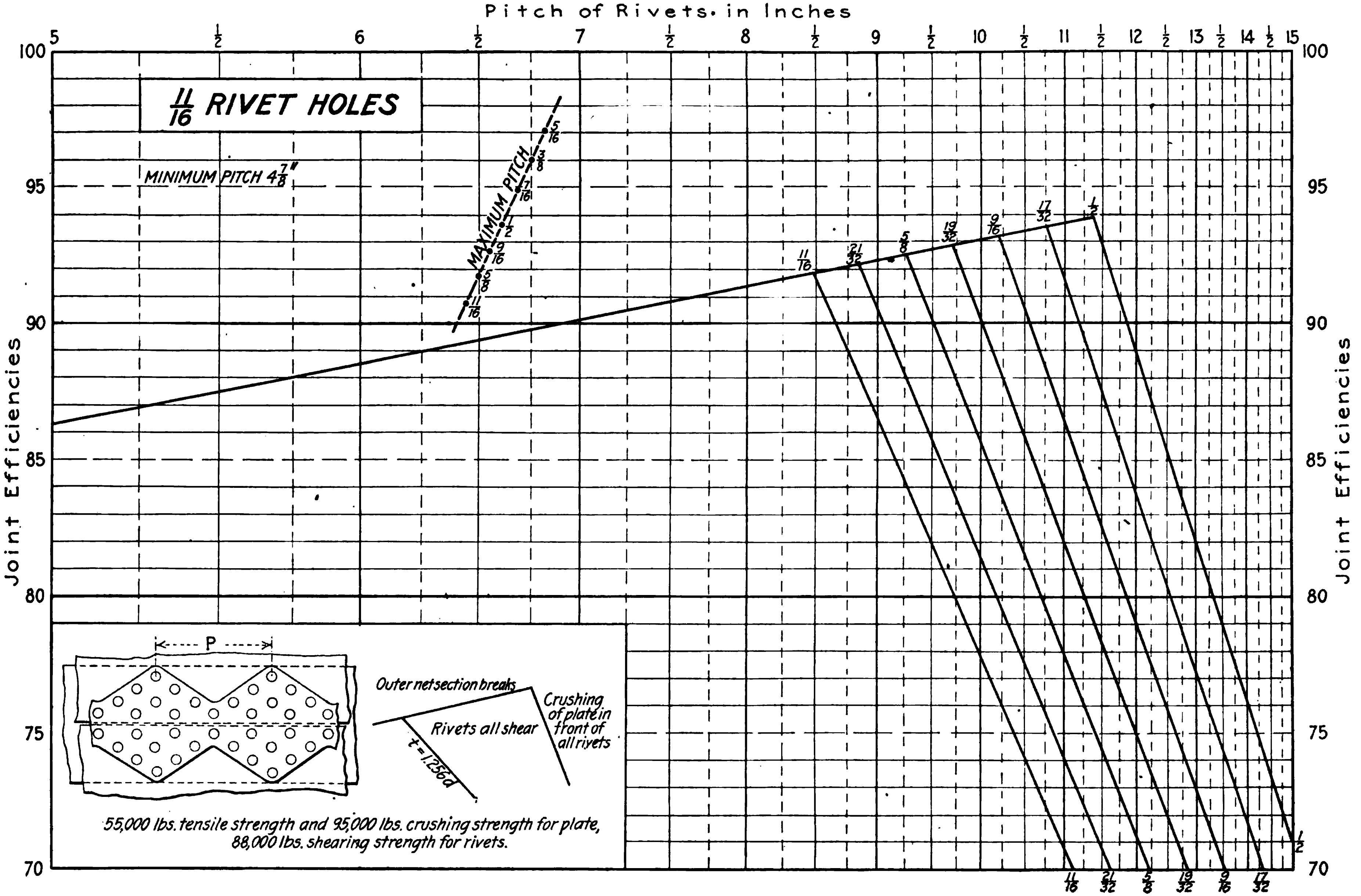

Pitch of Rivets in Inches
1 5/16 RIVET HOLES
MINIMUM PITCH 11 1/8"
MAXIMUM PITCH
Joint Efficiencies
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets

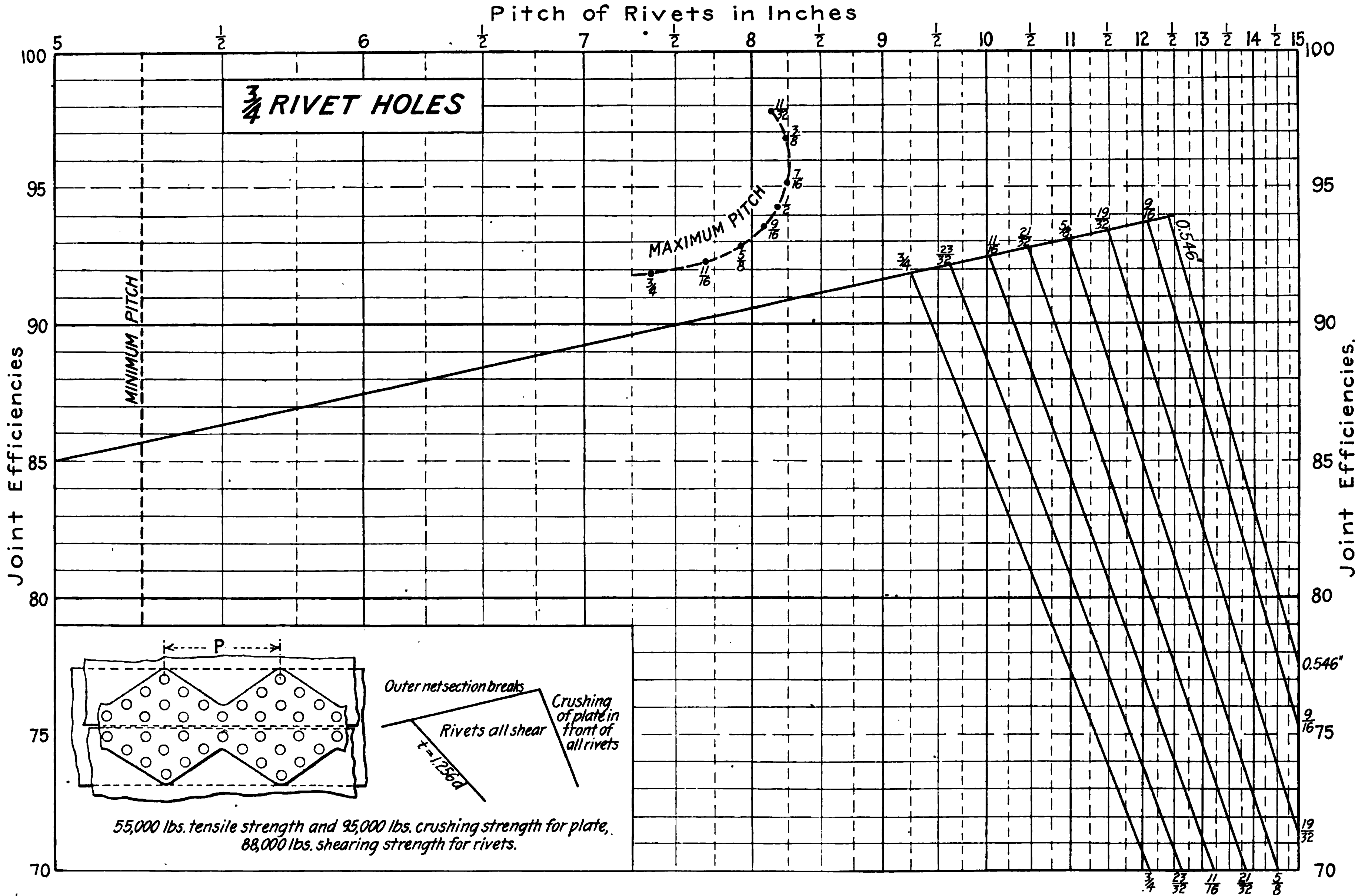

Pitch of Rivets in Inches
1 3/8 RIVET HOLES
MINIMUM PITCH 11 5/8"
MAXIMUM PITCH
Joint Efficiencies
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets


Pitch of Rivets in Inches
12
½
13
14
15
16
17
18
19
20
21
22
23
24
100
95
90
85
80
75
70
Joint Efficiencies
1 7/16 RIVET HOLES
MINIMUM PITCH 12"
MAXIMUM PITCH
21/32
11/16
3/4
13/16
0.903"
29/32
15/16
31/32
1
1 1/32
1 1/16
1 3/32
1 1/8
1 5/32
1 3/16
1 7/32
1 1/4
1 9/32
1 5/16
Outer net section breaks
Crushing of plate in front of all rivets
Crushing of plate at inner rivets and shearing of outer rivets
Section along B-B breaks and outer rivets shear
Rivets all shear
B
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate, 44,000 and 88,000 lbs. shearing strengths for rivets

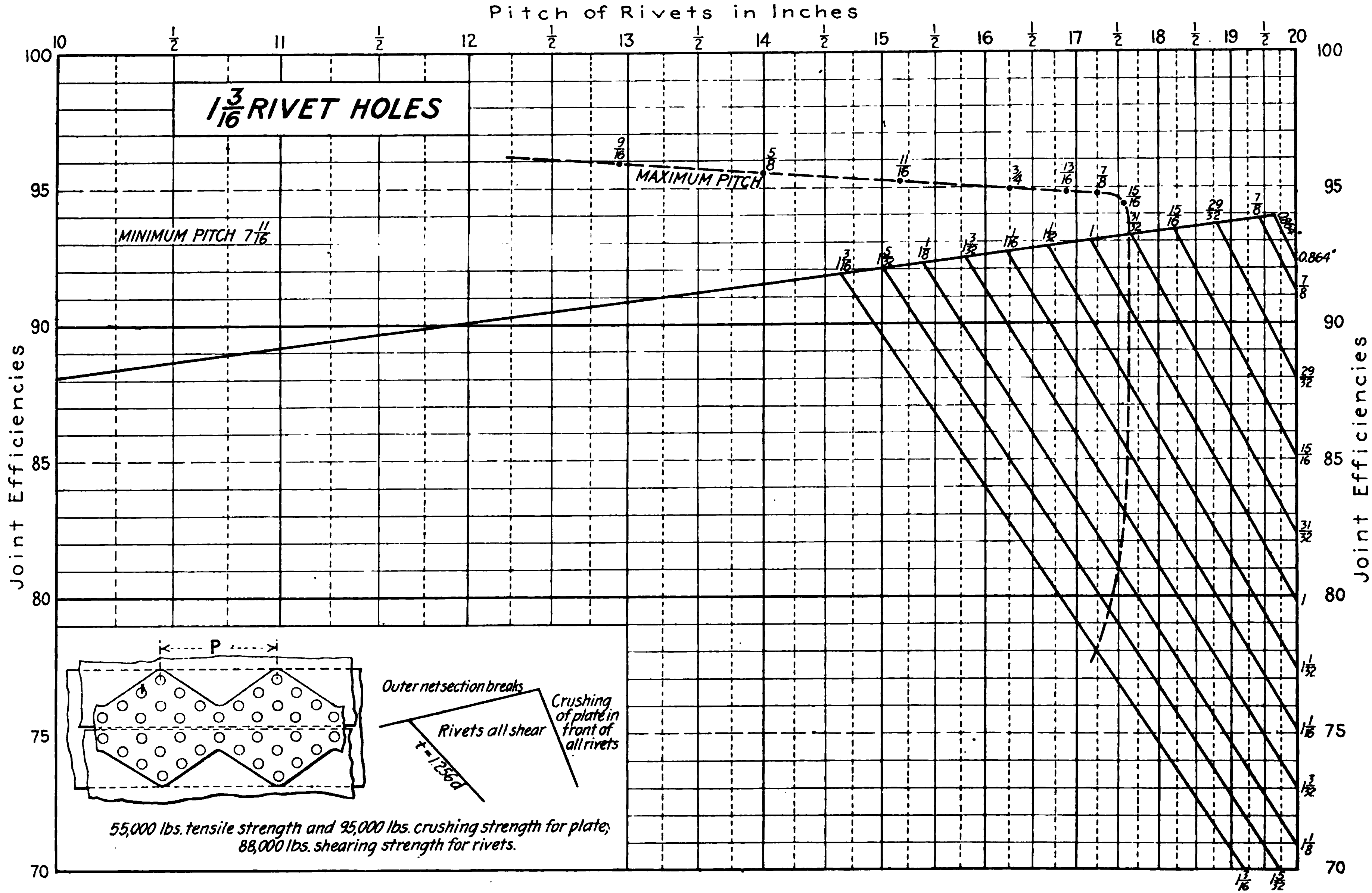

Pitch of Rivets in Inches
1½ RIVET HOLES
Joint Efficiencies
MINIMUM PITCH
MAXIMUM PITCH
Outer net section breaks
Section along B-B breaks and outer rivets shear
Rivets all shear
Crushing of plate at inner rivets and shearing of outer rivets
Crushing of plate in front of all rivets
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate. 44,000 and 88,000 lbs. shearing strengths for rivets

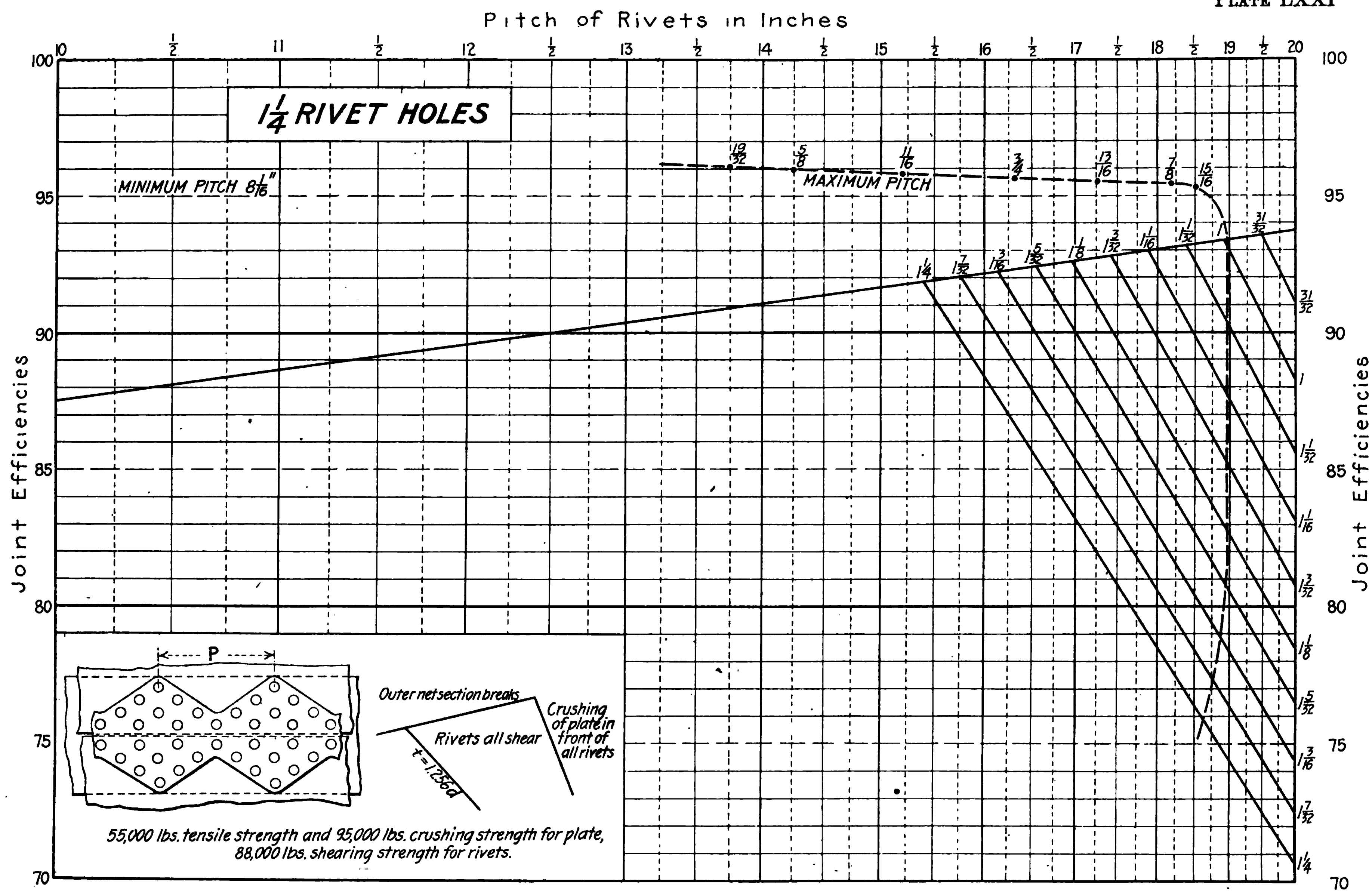

Pitch of Rivets in Inches
5
½
6
½
7
½
8
½
9
½
10
½
11
½
12
½
13
½
14
½
15
100
95
90
85
80
75
70
Joint Efficiencies
5/8 RIVET HOLES
MINIMUM PITCH 4½"
MAXIMUM PITCH
19/32
5/16
3/8
7/16
1/2
9/16
5/8
19/32
9/16
17/32
1/2
15/32
0.455"
P
Outer net section breaks
Rivets all shear
Crushing of plate in front of all rivets
t=1.256d
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate,
88,000 lbs. shearing strength for rivets.

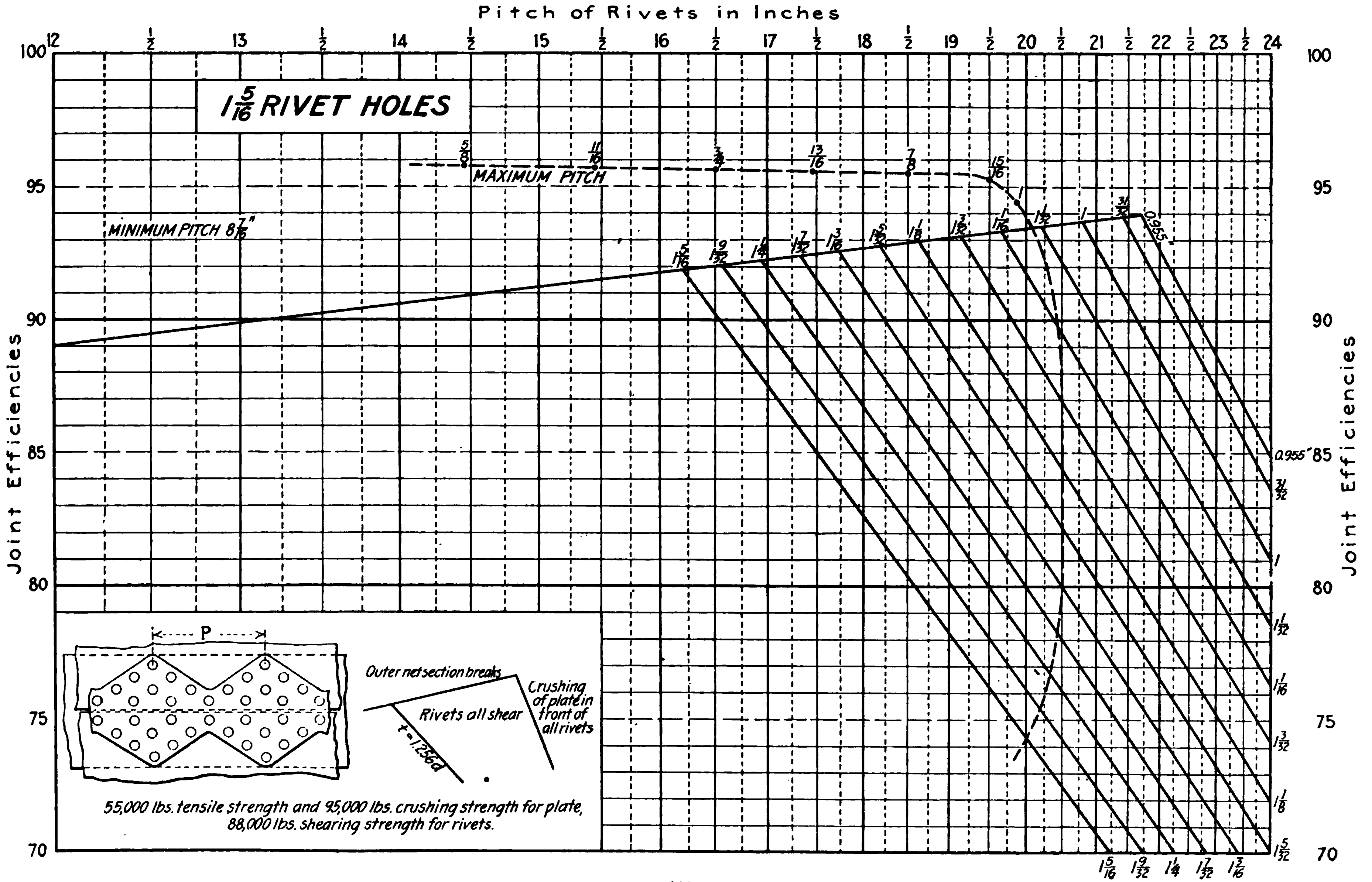

Pitch of Rivets in Inches
Joint Efficiencies
11/16 RIVET HOLES
MINIMUM PITCH 4 7/8"
MAXIMUM PITCH
Outer net section breaks
Rivets all shear
Crushing of plate in front of all rivets
t=1.25 d
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate,
88,000 lbs. shearing strength for rivets.

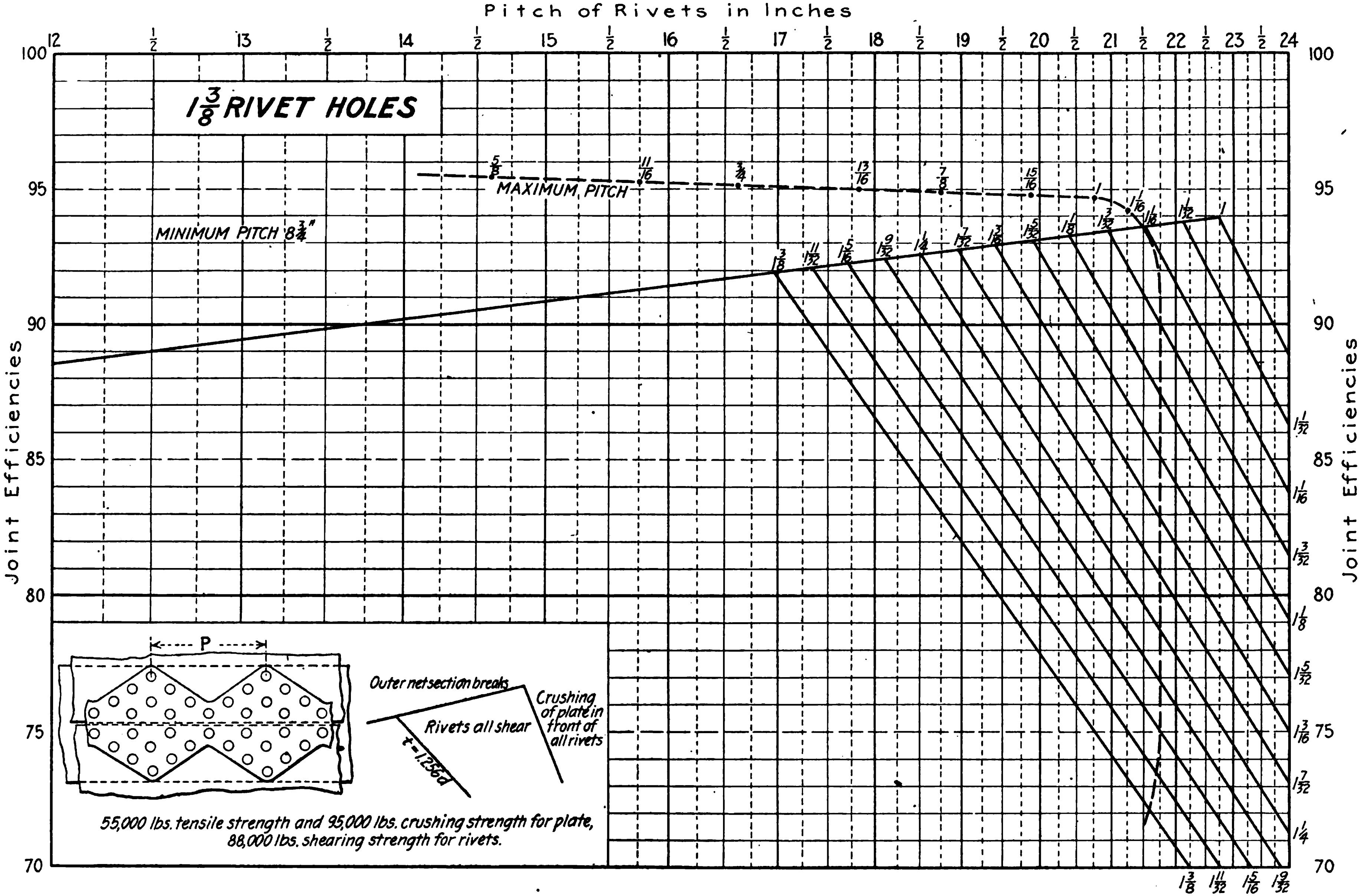


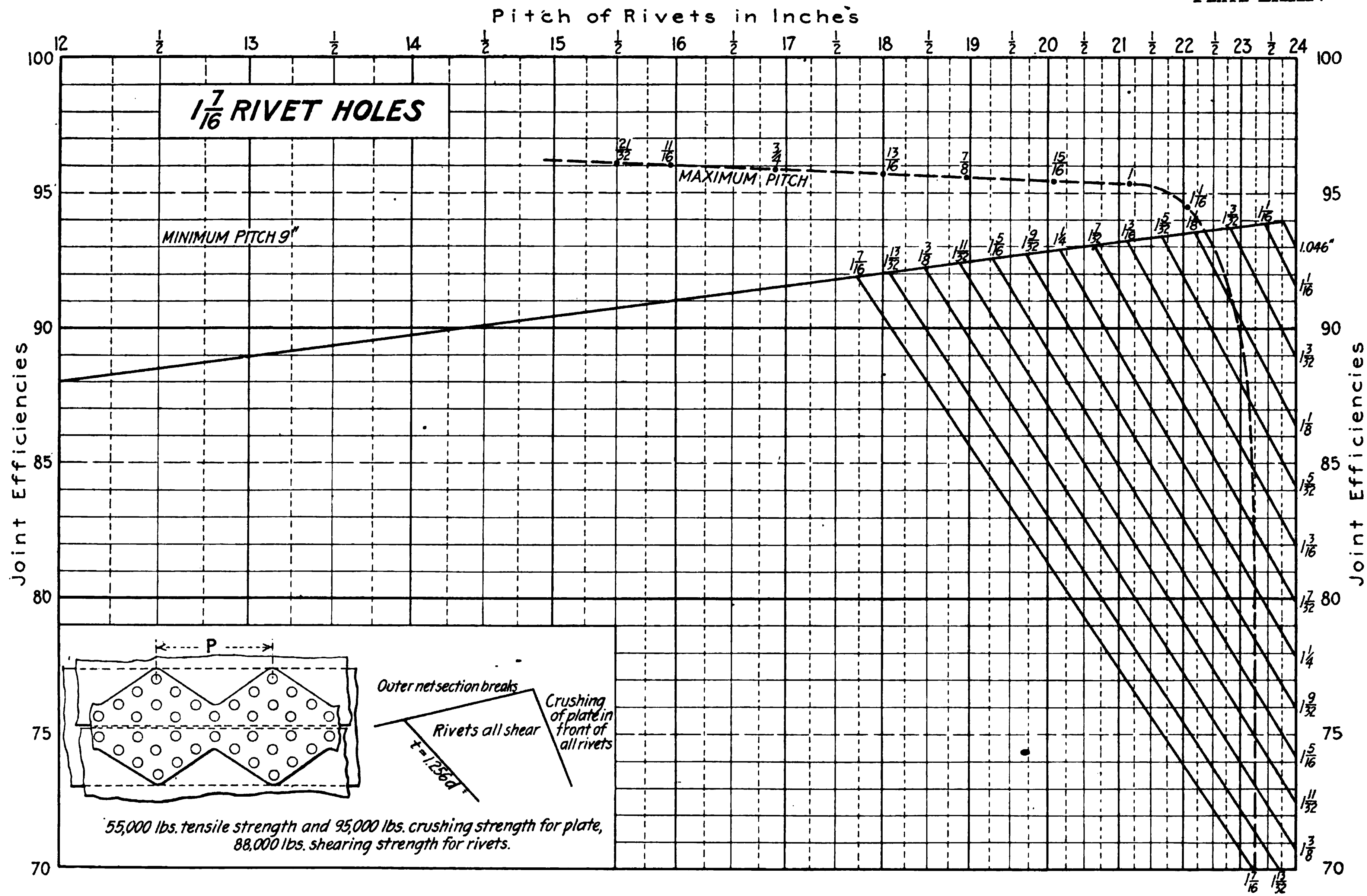
Pitch of Rivets in Inches
5
½
6
½
7
½
8
½
9
½
10
½
11
½
12
½
13
½
14
½
15
100
95
90
85
80
75
70
Joint Efficiencies
¾ RIVET HOLES
MINIMUM PITCH
MAXIMUM PITCH
0.546"
9/16
19/32
¾
23/32
11/16
21/32
5/8
P
Outer net section breaks
Rivets all shear
Crushing of plate in front of all rivets
t = 1.256 d
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate,
88,000 lbs. shearing strength for rivets.

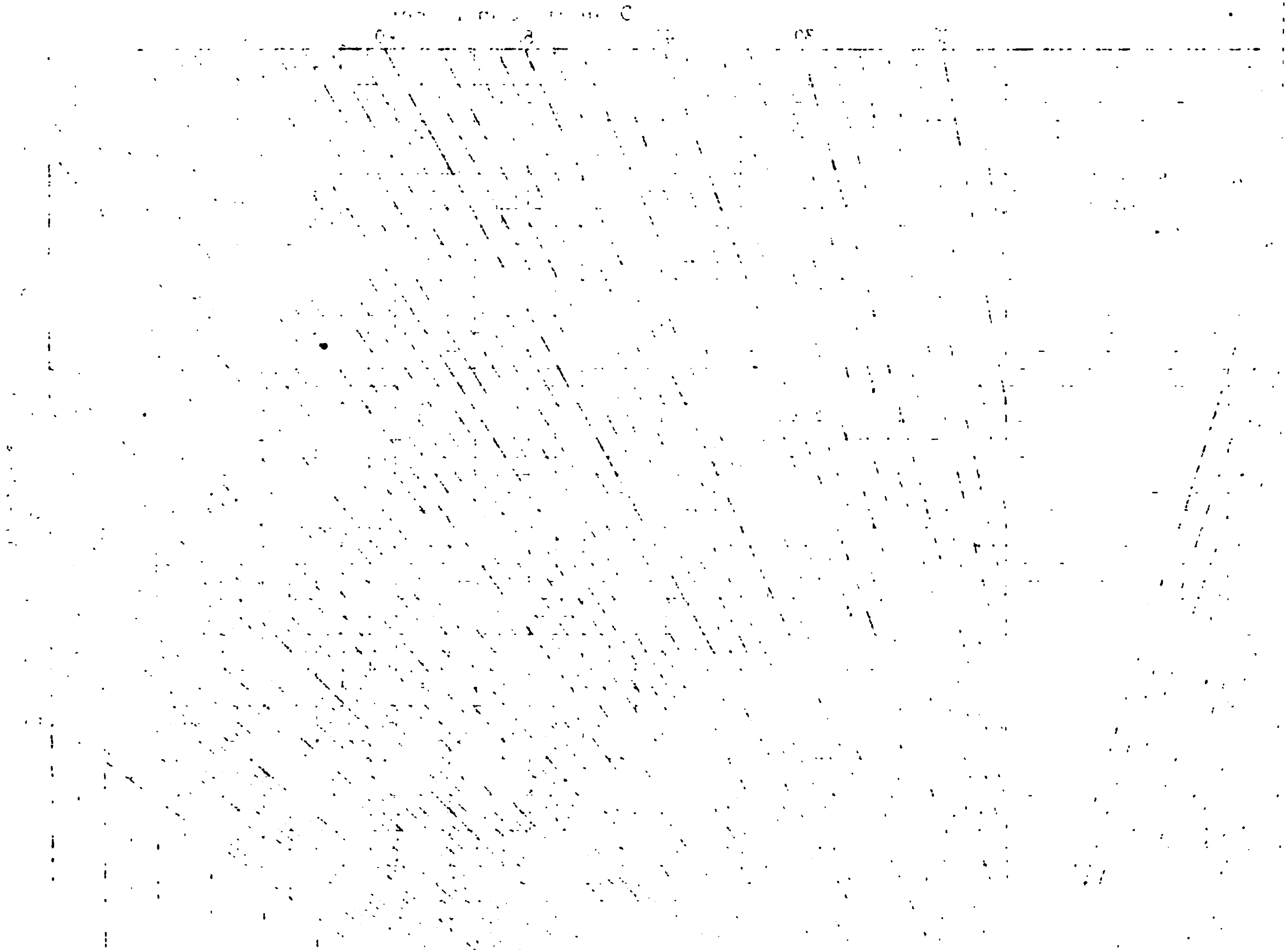

Pitch of Rivets in Inches
1 3/16 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 7 11/16
Joint Efficiencies
Outer net section breaks
Rivets all shear
Crushing of plate in front of all rivets
t = 1.256d
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate;
88,000 lbs. shearing strength for rivets.

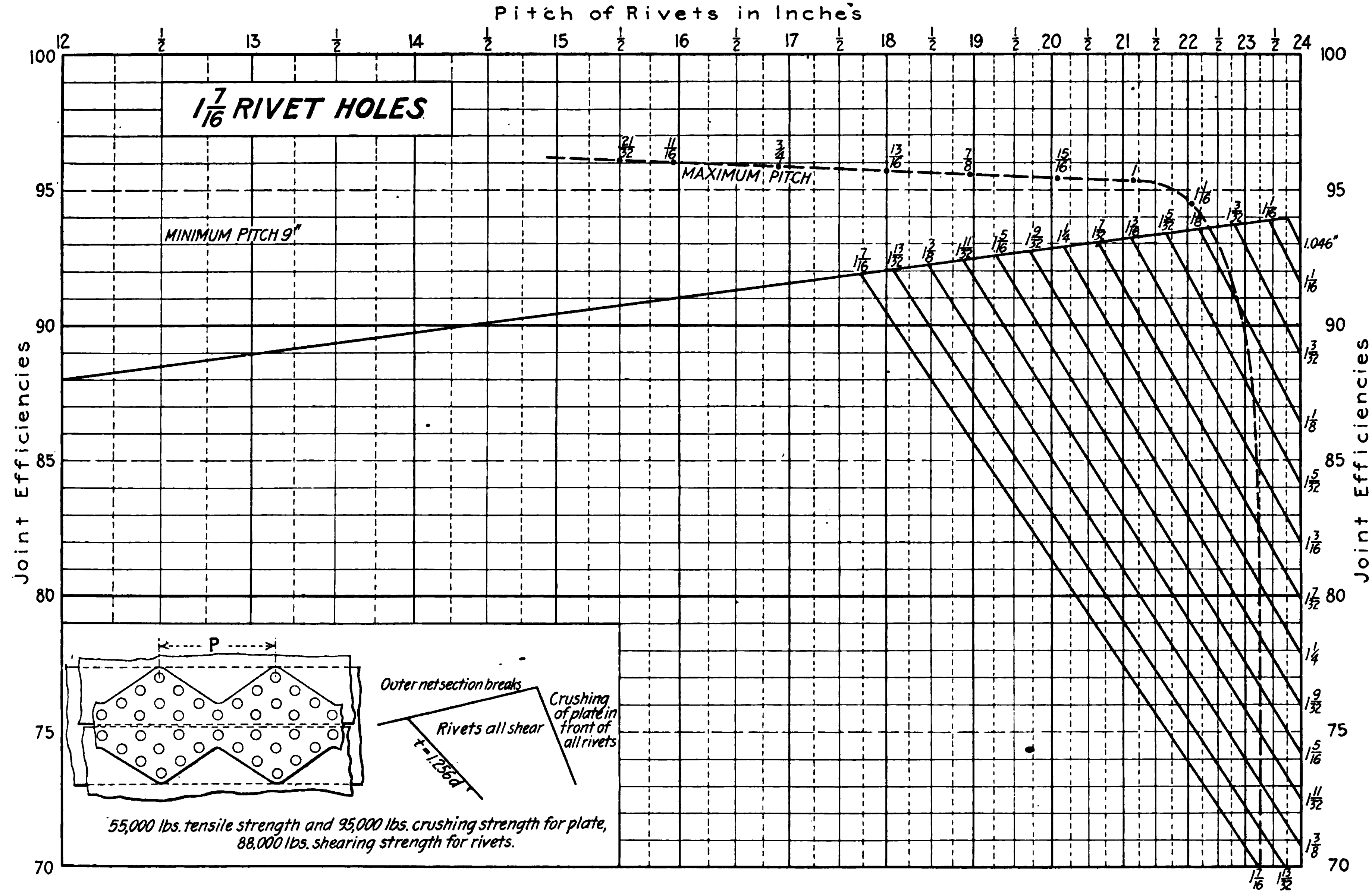

Pitch of Rivets in Inches
Joint Efficiencies
1 1/4 RIVET HOLES
MINIMUM PITCH 8 1/16"
MAXIMUM PITCH
Outer net section breaks
Rivets all shear
Crushing of plate in front of all rivets
t = 1.256d
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate,
88,000 lbs. shearing strength for rivets.


Pitch of Rivets in Inches
Joint Efficiencies
1 5/16 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 8 7/16"
Outer net section breaks
Rivets all shear
Crushing of plate in front of all rivets
t = 1.256d
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate,
88,000 lbs. shearing strength for rivets.


Pitch of Rivets in Inches
Joint Efficiencies
1 3/8 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 8 3/4"
P
Outer net section breaks
Rivets all shear
Crushing of plate in front of all rivets
t = 1.256d
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate,
88,000 lbs. shearing strength for rivets.


Pitch of Rivets in Inches
Joint Efficiencies
1 7/16 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 9"
1.046"
P
Outer net section breaks
Rivets all shear
Crushing of plate in front of all rivets
t=1.256d
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate,
88,000 lbs. shearing strength for rivets.




Pitch of Rivets in Inches
Joint Efficiencies
1 7/16 RIVET HOLES
MAXIMUM PITCH
MINIMUM PITCH 9"
1.046"
Outer net section breaks
Rivets all shear
Crushing of plate in front of all rivets
P
t = 1.256d
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate,
88,000 lbs. shearing strength for rivets.

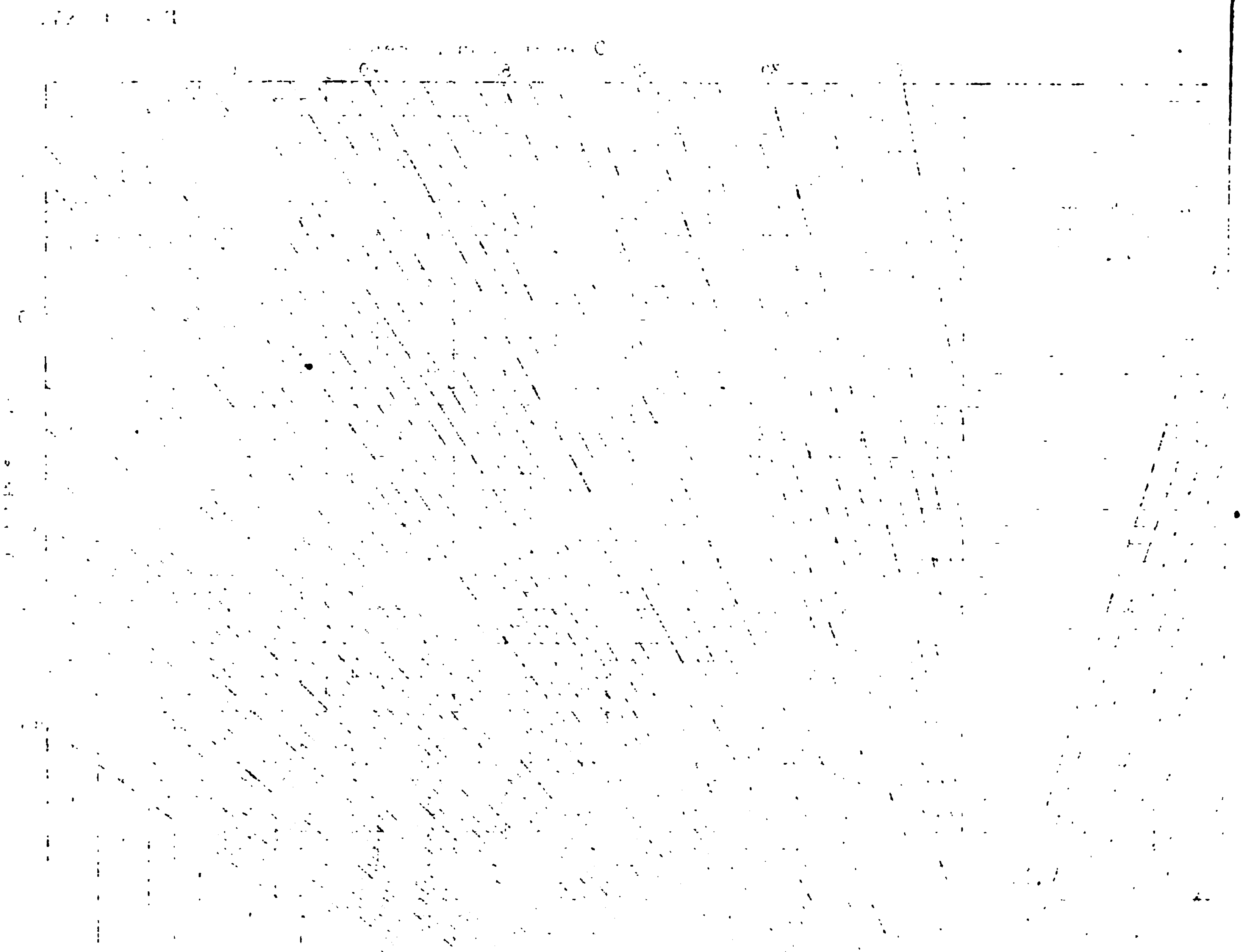
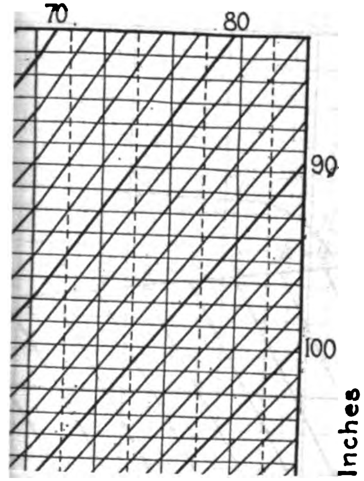
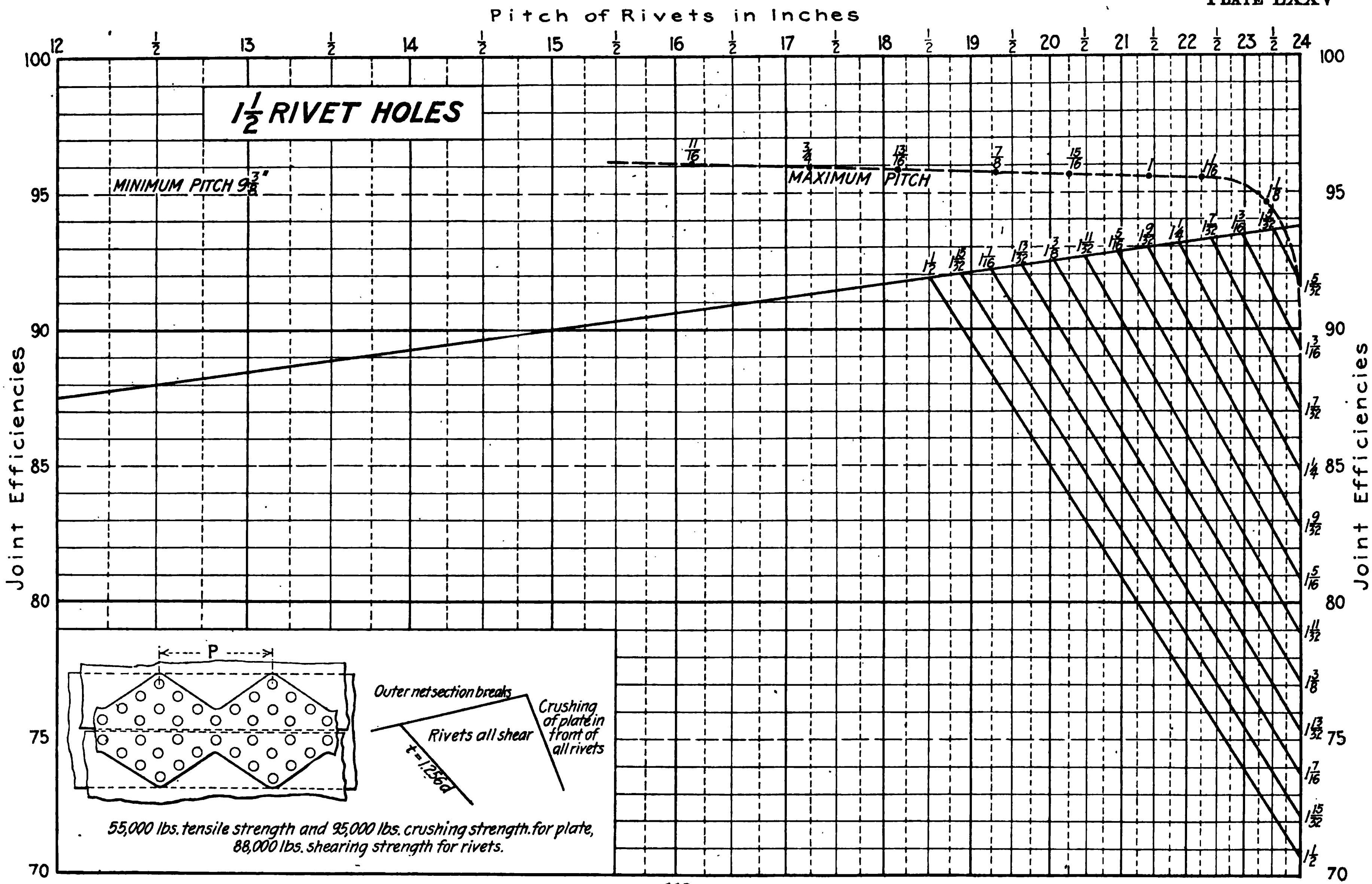


PLATE LXXVI




Pitch of Rivets in Inches
Joint Efficiencies
1½ RIVET HOLES
MINIMUM PITCH 9⅜"
MAXIMUM PITCH
Outer net section breaks
Rivets all shear
Crushing of plate in front of all rivets
t=1.256d
P
55,000 lbs. tensile strength and 95,000 lbs. crushing strength for plate,
88,000 lbs. shearing strength for rivets.

CHAPTER IX

MAKING JOINT DIAGRAMS

For the student interested in knowing how the diagrams giving the efficiencies of riveted joints are made and why they are correct the following explanation is given. The author assumes that the reader is familiar with analytical geometry, but a later explanation shows how such diagrams may be made and requires only a knowledge of arithmetic and the ability to solve simple equations.

DIAGRAMS FOR LAP AND BUTT-STRAP JOINTS WITH STRAPS OF EQUAL WIDTH

The equations giving the efficiency of a single-riveted lap joint (see page 23) are:

$$E = \frac{(P - d)tT}{PtT}$$

$$E = \frac{0.7854d^2S}{PtT}$$

$$E = \frac{tdC}{PtT}$$

and the equations giving the efficiency of all lap joints and those of the butt-strap type with straps of equal width are of the same form. By reducing the above equations to their simplest form and writing them thus:

$$E = 1 - \left(\frac{1}{P}\right)d \qquad (1)$$

$$E = \left(\frac{1}{P}\right)\frac{0.7854d^2S}{tT} \qquad (2)$$

$$E = \left(\frac{1}{P}\right)\frac{dC}{T} \qquad (3)$$

it is seen that they are all of the form representing straight lines when E and P are variables and the values for P are reciprocal values and not the direct values of this variable, and when the values of d and t are

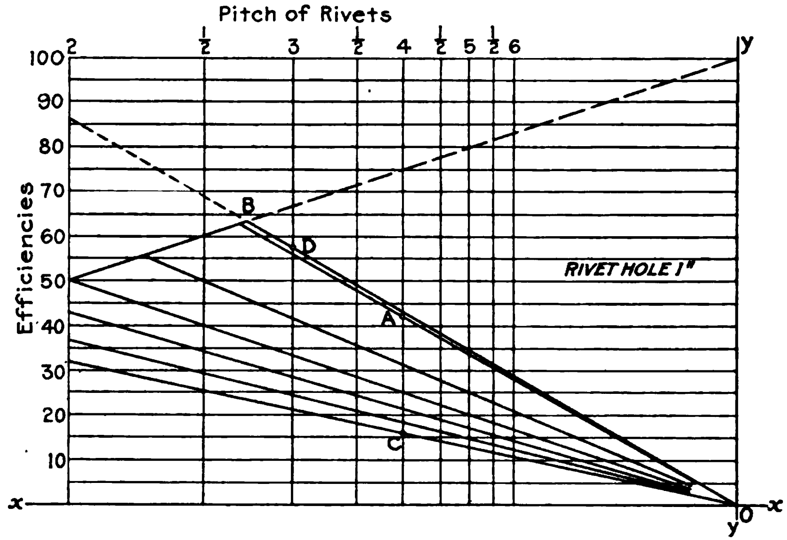


FIG. 29.—How a diagram is made for a single-riveted lap joint.

constant; T, S and C represent constant values in the calculations for the efficiency of a riveted joint. Therefore to make a diagram showing the values for efficiency as given by the three equations for a single lap-riveted joint by means of straight lines, it is necessary to first prepare

a sheet as shown in Fig. 29, which is done as follows. Assume that the lowest value of P to be considered is 2 in., and that the width of the paper is such that the vertical lines at each side may be 20 in. apart. After drawing these two vertical lines, a number of horizontal lines should be drawn to represent efficiencies, and these may be laid off to any convenient scale. The bottom line, representing zero efficiency, should be made the axis of x, and the last vertical line to the right the axis of y. Then since the distances along the axis of x are to represent reciprocal values of P, the distance to the vertical line representing 2-in. pitch (on the left) will be the reciprocal of 2 to the scale to which the diagram is made, and since this distance is 20 in. the distance from the axis of y to a vertical line which would represent unity, but not shown in Fig. 29, would be 40 in., as the reciprocal of 2 is ½, and since this is represent d by 20 n., unity would be represented by 40 in. when laid off to the same scale. To find the position of a vertical line representing any other pitch of rivets with respect to the axis of y, it is only necessary to divide 40 by the required pitch and the result will be the distance from the axis of y; as this operation is the same as multiplying the reciprocal of the pitch value by 40, which represents unity to the scale chosen to represent pitch values.

With the sheet prepared in this manner a diagram may be drawn for any given rivet-hole diameter, and for simplicity, it will be assumed that this diameter for the diagram under consideration is 1 in. Referring to equation (1) it is seen that when P becomes very large, the efficiency approaches unity, that is, a value of 100 per cent., as a maximum. As the axis of y represents an infinite pitch value, the point of intersection of the axis of y and the top line of the diagram representing 100 per cent. efficiency, will be one point on the line represented by equation (1), and another point on this line may be found by solving equation (1) for any value of P, say 2 in. For this pitch value and where d was 1 in., E would have a value of 50 per cent. The top line of the diagram may now be drawn, connecting the two points that have been found, and this line will represent all values for efficiency due to the mode of joint failure indicated by equation (1).

Referring to equation (3), it is seen that for a constant value of d, this equation represents a single line, intersecting the axis of y at 0, and that another point on this line may be readily determined by assigning the required values for P, C and T, and solving for E. Having found such a point as D it may be connected with the origin, as shown in Fig. 29. Since the two lines whose positions have been determined represent the joint efficiency by two of the three possible methods of failure, it is evident that the portion of each, lying above the point where they intersect (B, Fig. 29) and which is shown dotted in the figure, cannot be of service, since the line determining the lower efficiency is the one that governs.

By reference to equation (2), it is seen that this equation would represent a straight line, when d, S, T and t, were constant in value, and since the diagram being constructed is for one value of d (1 in.), equation (2) would represent one line for each value of t to be considered. It is also evident that all such lines would pass through the origin, that is, the intersection of the axis of y and the line representing zero efficiency. The lines representing efficiency by equation (2) that would lie above the line representing efficiency by equation (3), would not be of value in determining joint efficiency, and to determine the value of t where these two sets of lines would coincide, make (2) and (3) equal each other and solve for t, thus:

$$\frac{dC}{PT} = \frac{0.7854d^2S}{PtT} \text{ or } t = \frac{0.7854dS}{C}$$

Because, with decreasing values of t the efficiency as given by equation (2) increases, all values of t less than $\frac{0.7854dS}{C}$ need not be considered. By assigning various values for t greater than the above minimum value, a point on each of the lines representing the different plate thicknesses to be considered should be obtained, and connecting such points with the origin would produce a fan-shaped diagram as Fig. 29.

By referring to equation (2) it is seen that for any constant values of d and P, the efficiency will vary inversely as the value of t or directly as the reciprocal of t. Therefore, the distances between the points of

intersection of the lines representing equation (2) and any pitch line will be reciprocal values of t to some scale. This gives a simple and more accurate method for locating the position of the lines representing formula (2) than by calculating an intersection for each line. For example, by drawing a series of vertical lines at such distances from the axis of y that they would represent to any scale the reciprocals of values of t, as shown in Fig. 30, the distances between these vertical

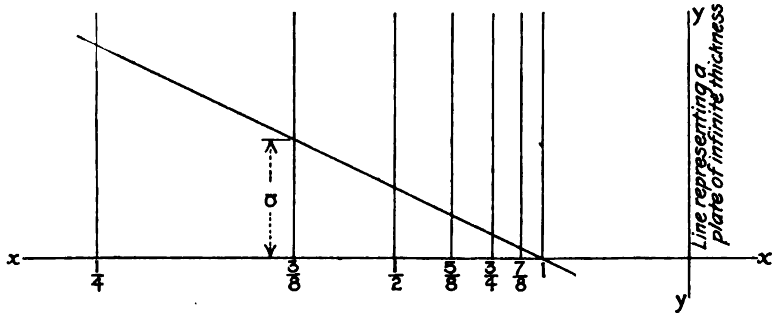


Fig. 30.—Use of reciprocals of plate thicknesses.

lines will have the same relation to each other as will the distances between the points of intersection of lines represented by formula (2) and any pitch line. All that is then required to obtain the points of intersection of the lines represented by equation (2) and any pitch line, is to calculate the value of the efficiency at the intersection for the thickest plate, and also for the thinnest plate considered, using the lowest fractional value of the thickness instead of the value of $t = \frac{0.7854dS}{C}$ and marking the points on the given pitch line, as at A and C, Fig. 29.

Now lay off above the base line on the line representing the thinnest plate (dimension a, Fig. 30) a distance equal to that between A and C, Fig. 29, drawing a diagonal line through this point to the intersection of the base line and the line representing the thickest plate considered, 1 in., as illustrated in Fig. 30. The distance from the base line on each vertical line representing plate thickness in Fig. 30, to each of the intersections with the diagonal line just drawn, will represent the distance above point C, Fig. 29, to the intersection of the several lines representing the different plate thicknesses by equation (2). In using this method of construction a line is not actually drawn across the sheet as in Fig. 30, as will be explained later, and the use of this method is really more simple than the explanation would indicate, and the saving in time and the gain in accuracy is very appreciable. The above explanation of how to draw a diagram for a single-riveted lap joint for one-rivet diameter will suffice as an explanation for the drawing of such diagrams for any rivet size, and also for the double-riveted joints of this type; the explanation will also serve for butt-strap joints where the straps are of equal width, as the equations representing the efficiency for all of these joints are of the same form.

In the diagrams given in this book for lap and butt-strap joints with equal width straps, one diagram is used for both types of joints. This was made possible because the assumed shearing strength of rivet material in double shear was twice the value used for single shear; if this relation between the shearing values had not existed, separate diagrams for lap joints and for butt-strap joints would have been required. It will be found possible in making diagrams to place the diagram for single- and double-riveting on the same sheet, since the range of plate thickness required for commercial joints will not overlap for the two types of riveting.

Diagrams for Butt-strap Joints with Straps of Unequal Width.—Referring to the equations giving the efficiencies for joints of this type (see page 24) it is seen that they are all of the same form, and an explanation of how a diagram may be made for the double-riveted joint of this form will suffice as an explanation for the making of diagrams for all joints of this type.

The equations giving the efficiencies for such joints are:

$$E = \frac{(P - d)tT}{PtT}$$

$$E = \frac{(P - 2d)tT + 0.7854d^2S}{PtT}$$

$$E = \frac{(P - 2d)tT + t_1dC}{PtT}$$

$$E = \frac{2 \times 0.7854d^2(2S) + 0.7854d^2S}{PtT}$$

$$E = \frac{2tdC + t_1dC}{PtT}$$

$$E = \frac{2tdC + 0.7854d^2S}{PtT}$$

To make diagrams giving the efficiencies of joints as indicated by the above formulas, it is necessary to eliminate consideration of t_1, the thickness of straps, separately from t, the thickness of the plate, for if the strap thickness was to be considered there would be involved the making of many more diagrams covering the various strap thicknesses in combination with the different plate thicknesses over the range where formulas (3) and (5) would govern the efficiency. By eliminating consideration of strap thickness, the only limitation placed on the diagrams is that they do not show the joint efficiency where the strap thickness is less than $\frac{0.7854dS}{C}$, unless the strap thickness is equal to or greater than the plate thickness. Since this limit to strap thickness is less than used in commercial boiler joints, the limitations imposed on the diagrams by omitting consideration of the strap thickness, except as indicated above, is not of importance. Rewriting the above equations in their simplest form and changing t_1 to t, the result would be as follows:

$$E = 1 - \frac{d}{P} \tag{1}$$

$$E = 1 - \frac{2d}{P} + \frac{0.7854d^2S}{PtT} \tag{2}$$

$$E = 1 - \frac{2d}{P} + \frac{dC}{PT} \tag{3}$$

$$E = \frac{2 \times 0.7854d^2(2S) + 0.7854d^2S}{PtT} \tag{4}$$

$$E = \frac{3dC}{PT} \tag{5}$$

$$E = \frac{2dC}{PT} + \frac{0.7854d^2S}{PtT} \tag{6}$$

Studying formulas (1) and (3) shows that the efficiency as given by each would be equal if C was equal to T. Where C is greater than T, as is always the case, the efficiency as given by formula (1) would be the smallest of the two and therefore the governing formula in determining the efficiency where the thickness of the straps is not considered.

From the foregoing, formula (3) may be eliminated, and there remain only five formulas to be considered. Examining formulas (1), (2), (4), (5) and (6), it is seen that with constant values for d, S, T, C, and t, they would all represent straight lines if the reciprocal values of P were used for this variable instead of direct values, as was the case in diagraming the single-riveted lap joints.

Line Representing Efficiencies Due to Breaking of Plate between Outer Rivet Holes.—Preparing a sheet with lines to represent the reciprocal values of P over the proper range, as in Fig. 31, and as was explained for lap-riveted joints, the diagram may be made. Examining formula (1), it is seen that as the value of P increases, the efficiency approaches 100 per cent., as was the case with the lap joints, and therefore the intersection of the axis of y with the top line representing 100 per cent. is a point on the line representing this equation. Assuming the value for d for the diagram under construction as 1, another point on the line represented by formula (1) where it cuts the pitch line representing 4 in. is at $E = 1 - \frac{1}{4}$ or 75 per cent. Connecting these two points would give a line representing all the values for efficiency as determined by formula (1).

Lines Representing Efficiencies Due to Breaking of Plate between Rivet Holes in Second Row and Shearing of Outer Rivets.—Referring to formula (2), the lines represented by this formula would pass through the intersection of the axis of y and the line representing

100 per cent. efficiency, the same as for formula (1), for as the value of P approaches infinity, the efficiency approaches 100 per cent. as a limit. Another point on any line represented by this formula may be

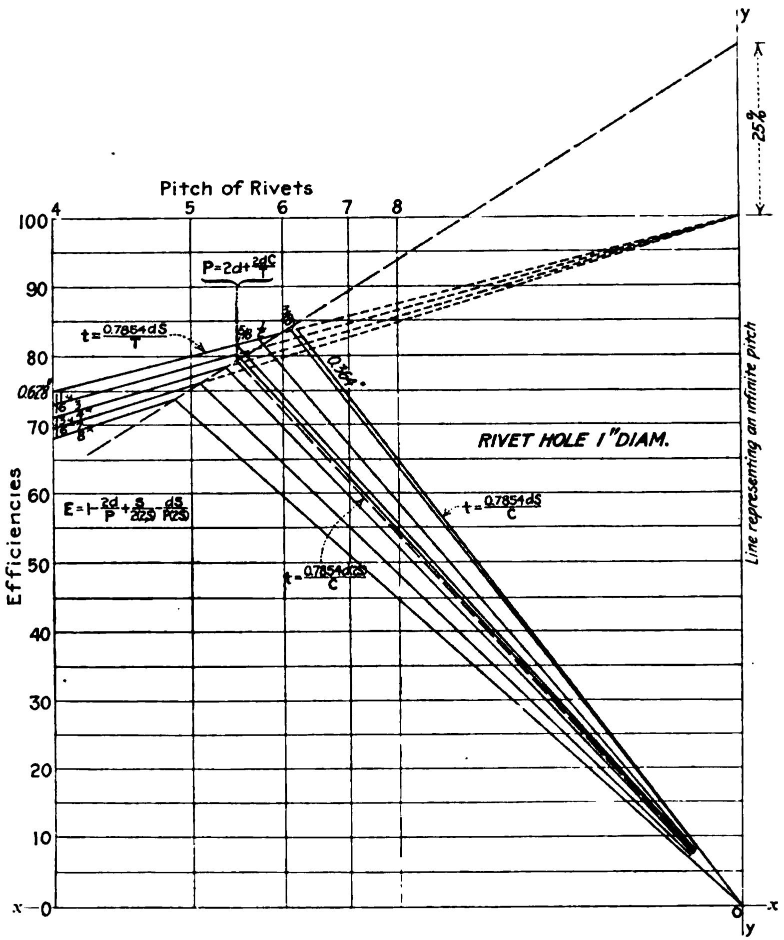


FIG. 31.—How a diagram is made for a double-riveted butt-strap joint with straps of unequal width.

calculated for any value of P, by assuming a fixed value for t, and by the same procedure for each value of t all the lines necessary to represent efficiencies due to the method of failure represented by formula (2) could be located. It is evident that since increases in the value of t decrease the efficiency as given by formula (2), for plate thicknesses less than that where the efficiency given by (1) or (2) is equal, the efficiency by formula (1) would govern. This is the same as stating that none of the lines giving the efficiency as determined by formula (2) lying above the line just drawn for formula (1) will be of service. Making formulas (1) and (2) equal to each other and solving for t:

$$1 - \frac{1}{P} = 1 - \frac{2d}{P} + \frac{0.7854d^2S}{PtT} \text{ or } t = 0.7854d\frac{S}{T}.$$

It is seen that where t is not over $0.7854d\frac{S}{T}$, the top line of the diagram would represent the efficiency, and where S is 44,000 lb. and T is 55,000 lb. and d is 1, this value of t would be 0.62832. The left end of the top line should be labelled this value to show that it does not represent efficiencies for greater values of t. Assuming values of t greater than the above, the intersection of lines representing the efficiencies of the joint as determined by formula (2) may be obtained for any pitch of rivets, and lines connecting these points with the intersection of the 100 per cent. efficiency line and the axis of y, may be drawn as shown in Fig. 31. As the values for efficiency as determined by formula (2) vary as the reciprocal of the plate thickness, the same short cut may be taken advantage of as in the case of the lap-riveted joints. Two efficiencies, one for the thickest and one for the thinnest plates considered, may be calculated for a single pitch value, and by means of a sheet laid off as in Fig. 30, the intermediate values may be determined without calculation.

Lines Representing Efficiencies due to Shearing of all Rivets, both in Double and in Single Shear.—Omitting consideration of formula (3), for the reasons given above, and examining formula (4), notice that with increasing values of P, the efficiency decreases and approaches

zero as a limit. Therefore, the intersection of the axis of y and the bottom line of Fig. 31, representing zero efficiency, would be one point on any line drawn to represent the values of efficiency as determined by formula (4). It is also evident that the values as given by this equation vary as the reciprocal of t, and by calculating the efficiency for the thickest and thinnest plates considered, the intermediate values may be obtained from Fig. 30.

The lines representing efficiency by equation (4) will cross those previously drawn on Fig. 31. It is evident that lines representing formulas (5) and (6) would lie in the same direction as those for formula (4).

To determine the minimum plate thickness required for efficiencies by formula (4), the formula should be made equal to (6) and solved for the value of t, thus:

$$\frac{2 \times 0.7854d^2(2S) + 0.7854d^2S}{PtT} = \frac{2dC}{PT} + \frac{0.7854d^2S}{PtT} \text{ or } t = \frac{0.7854d(2S)}{C}$$

Where d is 1 and $(2S)$ and C are 88,000 and 95,000 respectively, the value of t would become 0.7275, or little more than $^{23}/_{32}$ in. Making equations (4) and (5) equal each other, and solving for t, it is found that the value of t, where the efficiency as found by these two equations would be the same, is

$$t = \frac{0.5236d(2S) + 0.2618dS}{C}.$$

Since the shearing strength of rivets in single shear is necessarily less than in double shear, it will be noted that the value of t just obtained is less than

$$\frac{0.7854d(2S)}{C}.$$

Since the sum of the numerical coefficients in the numerator equals 0.7854, and therefore, the latter value of t is the one indicating the limit for joint efficiencies as determined by formula (4), for with any value of t less than this the efficiency would be governed by the method of failure indicated by either formula (5) or formula (6).

Obtaining values for equation (4) (for the different plate thicknesses) greater than $t = \dfrac{0.7854d(2S)}{C}$, and drawing lines connecting these points with the intersection of the axis of y and the zero efficiency line, completes this portion of the diagram. It is evident that the last lines drawn should not extend beyond those representing the same plate thicknesses, as determined by formula (2), for beyond these intersections the lines would represent higher values for efficiencies than would be represented by the lines for formula (2), and therefore would not govern the joint efficiency, also for the same reason the portion of the lines representing the value of equation (2) lying beyond these intersecting points will be of no value in determining the joint efficiency. These lines have therefore been drawn dotted.

Lines Representing Efficiencies Due to Crushing of Plate at Inner Rivets and Shearing of Outer Rivets.—In the above calculations in reference to the respective values for efficiency as determined by formulas (5) and (6), it is evident that the next method of joint failure to be considered is that indicated by formula (6). It is also seen from the portion of the diagram thus far constructed, and as shown in Fig. 31, that the lines representing equation (6) and those representing equation (2) will intersect. Making equations (2) and (6) equal each other. Solving for the value of P we have:

$$1 - \frac{2d}{P} + \frac{0.7854d^2S}{PtT} = \frac{2dC}{PT} + \frac{0.7854d^2S}{PtT} \text{ or } P = 2d + \frac{2dC}{T}$$

From this it is seen that the thickness of plate is not a factor in determining whether equation (2) or (6) would govern the efficiency of a joint, but that when the pitch of rivets is greater than the above value as determined for P, equation (6) would govern rather than equation (2), for as the value of P increases the value of (6) decreases, while the value of (2) increases. Therefore, efficiencies as given by (2) would be higher than those given by (6), and conversely for values of P less than $2d + \dfrac{2dC}{T}$. All lines representing values for equation

(2) beyond $P = 2d + \frac{2dC}{T}$ would have no significance in determining the joint efficiency. This portion of the line representing $1\frac{1}{16}$-in. plate has been drawn dotted to indicate this fact. Making equations (5) and (6) equal each other and solving for t, we have:

$$\frac{3dC}{PT} = \frac{2dC}{PT} + \frac{0.7854d^2S}{PtT} \text{ or } t = \frac{0.7854dS}{C}$$

which shows that if the values of t are less than this, the efficiency of the joint as determined by formula (6) would no longer govern; therefore, the lines determining the values of efficiency due to failure as indicated by formula (6) are to be located by using values of t between $t = \frac{0.7854dS}{C}$ and $t = \frac{0.7854d(2S)}{C}$, from which it will be evident that the minimum value of t to be considered is one-half the maximum, when the shearing strength in double shear is taken at twice that in single shear. With such relations between the shearing strengths, it is simplest to obtain the minimum value by dividing the maximum by 2. For constant values for d, T, C and S, the efficiency as determined by (6) varies as the reciprocal of t. Therefore, by locating points on a given pitch line by considering the maximum and minimum fractional values of plate thickness t, the intermediate points indicating the intersections of other lines representing plate thicknesses between these limits may be determined without calculation by means of Fig. 30. It is evident that no intersections of lines representing efficiencies by formulas (2) and (6), can be in a portion of the diagram determining joint efficiencies because formula (6) does not become effective until t is less than $\frac{0.7854dS}{C}$, and formula (2) ceases to be effective when t is less than $\frac{0.7854dS}{T}$, which is seen to be the larger value, when C is greater than T, as is always true of riveted joints.

Lines Representing Efficiencies Due to Crushing of Plate in Front of All Rivets.—Referring to formula (5), representing joint efficiency by the above method of failure, it will be noted that it is independent of plate thickness, that is, the efficiency of all joints for a given pitch of rivets and for any plate thickness and pitch where this method of joint failure would govern, will be the same, as in the case of the breaking of the outer net section of the plate as given by formula (1). Therefore, the efficiencies of all such joints are indicated by a single line.

Diagrams for Other Butt Joints with Straps of Unequal Widths.—Examining the equations for all such joints, it will be noticed that they are of the same form as those for the double-riveted joint of this type that has just been considered, and the making of a diagram for any given rivet-hole diameter would be proceeded with in the manner described above. It is, of course, necessary to have a separate diagram for each rivet-hole diameter, for unless one constant value for d is used in making a diagram, the equations would represent surfaces instead of lines.

Maximum Joint Efficiency.—The maximum joint efficiency, as will be seen in Fig. 31, is at the intersection of the lines representing the efficiency by formulas (1) and (5), or where $1 - \frac{d}{P} = \frac{3dC}{PT}$; that is, where $P = \frac{3dC}{T} + d$. Substituting this value for P in formula (1), the maximum efficiency is seen to be $E = \frac{3C}{3C + T}$. It will be noted that the equation giving the maximum efficiency is independent of the rivet diameter, that is, the peak of all diagrams representing different-sized rivet holes for one type of joint will be at the same height, where C and T are not varied in value.

Division Line of Diagram.—Examining the diagrams giving the efficiencies of joints of the butt-strap type with straps of unequal width, the intersections of the lines representing the efficiencies by breaking of the inner net section of plate and the shearing of outer rivets, or the shearing of all rivets form a straight line across the sheet. If the location of this line could be predetermined it would be an aid in drawing the diagrams or checking their accuracy. It is evident that

the value of t, for these intersections, in terms of the other variables, can be obtained by making equations (2) and (4) equal each other and solving for t, which would result, for the double-riveted joint, as follows:

$$1 - \frac{2d}{P} + \frac{0.7854d^2S}{PtT} = \frac{2 \times 0.7854d^2(2S)}{PtT} + \frac{0.7854d^2S}{PtT}$$

or

$$t = \frac{1.5708d^2(2S)}{T(P-2d)}.$$

Substituting this value of t in equation (4), results in

$$E = 1 - \frac{2d}{P} + \frac{S}{2(2S)} - \frac{dS}{P(2S)}$$

which represents the joint efficiency at any point where the efficiency by equations (2) and (4) become equal to each other. Notice from this last equation that as the value of P becomes very large and approaches infinity, the second and third members of the right-hand side of the equation become zero, and the value of the efficiency becomes, $E = 1 + \frac{S}{2(2S)}$, which gives the intersection of the axis of y with the line passing through the intersections of the lines represented by formulas (2) and (4). When the values of S and $(2S)$ is 44,000 lb. and 88,000 lb. respectively, this value of E would become 1.25, or 125 per cent. above the point where the zero efficiency line cuts the axis of y. To draw the line lying on the points of intersection between lines representing the joint efficiency by formulas (2) and (4), it is necessary to calculate only the point of intersection of the lines representing one plate thickness, preferably the thickest plate, and connect this point with the one found on the axis of y. The intersection of the dotted line representing $t = \frac{0.7854d(2S)}{C}$, with the pitch line representing $P = 2d + \frac{2dC}{T}$ (see Fig. 31), would lie on the line of intersections just found. The length of the dotted portion of this pitch line is the same for all diagrams giving the joint efficiency for the different rivet-hole diameters for one type of joint. If the position of this line is accurately determined for each rivet-hole diameter for a given joint, one point on the top line of the diagram and the position of line, $t = \frac{0.7854d(2S)}{C}$, would have to be determined for one rivet-hole size only. The line, $P = 2d + \frac{2dC}{T}$, could then be drawn for any diagram without further calculation for position or length, and its top and bottom extremities would serve to locate the top line and the line representing $t = \frac{0.7854d(2S)}{C}$.

Owing to the greater accuracy secured by calculating the values for each rivet-hole diameter separately, the above was not considered in making the diagrams except as a check for accuracy. It will be noted, that lines representing

$$t = 0.7854d\frac{S}{T},$$

$$P = 2d + \frac{2dC}{T},$$

$$E = 1 - \frac{2d}{P} + \frac{S}{2(2S)} - \frac{dS}{P(2S)},$$

$$t = \frac{0.7854d(2S)}{C}$$

$$t = \frac{0.7854dS}{C},$$

divide the diagrams into sections indicating the joint failure governing the joint efficiency (see Fig. 31).

DETERMINING SIZE OF DIAGRAM AND OBTAINING RECIPROCAL VALUES

Where W = width of diagram of reciprocal values to be considered, which will be determined by the size of paper or drawing board to be used.

x = distance in inches from the axis of y to the minimum value of plate thickness in laying off a sheet repre-

senting reciprocals of plate thicknesses or pitch, in the case of joint diagrams.

y = distance in inches from the axis of y to the maximum value of plate thickness or pitch as may be required.

b = base number, or the number which divided by any number would give the measure of the distance from the axis of y that would represent the reciprocal of

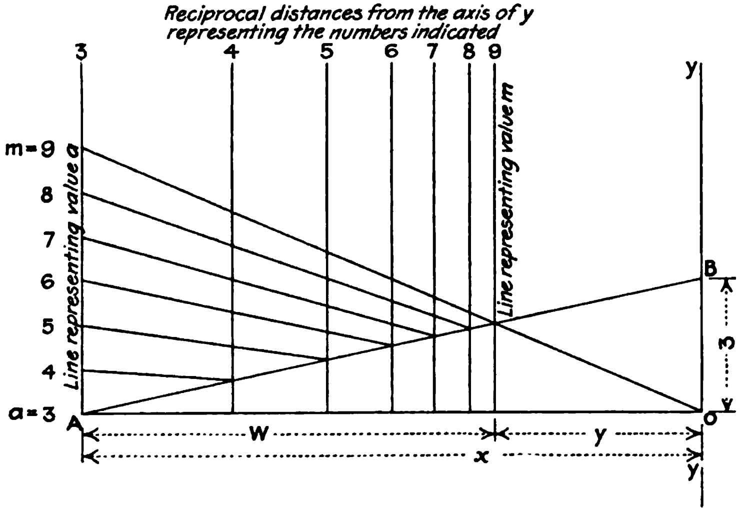


FIG. 32.—Graphical determination of reciprocal values.

that number, measured in the same units as the distances x or y; *i.e.*, b is the distance representing unity or the reciprocal of 1 to the scale used.

a = minimum number to be considered, *i.e.*, the number whose reciprocal value is to be represented by the distance x.

m = maximum number to be considered, *i.e.*, the number whose reciprocal value is to be represented by the dimension y.

The above values are shown on Fig. 32, and from the following relations between them the size of any diagram to be made can be quickly determined:

$$b = \frac{amW}{m - a} \tag{1}$$

$$x = \frac{mW}{m - a} \text{ or } \frac{b}{a} \tag{2}$$

$$y = \frac{aW}{m - a} \text{ or } \frac{b}{m} \text{ or } x - W \tag{3}$$

Assume that it is desired to make a diagram of 20 in. in width for a butt-strap joint with straps of unequal width, the maximum pitch value to be 9 in. and the minimum 3 in. The value W would then equal 20 in.; a, 3 in.; and m, 9 in. From formula (1),

$$b = \frac{3 \times 9 \times 20}{9 - 3} = 90,$$

and

$$x = \frac{90}{3} = 30 \text{ in.},$$

and

$$y = \frac{90}{9} = 10 \text{ in.}$$

To draw a diagram to this scale the drawing board would have to be wide enough to place the axis of y and the vertical line representing the 3-in. pitch value 30 in. apart, and if the board was not of such proportions as to permit locating these lines that distance apart a diagram narrower than 20 in. would have to be selected.

The position of the lines representing intermediate pitch values could be determined with respect to the axis of y by dividing the value of b—90 in this case—by each of the pitch values to be considered.

Since the laying off of reciprocal values for the pitches and plate thicknesses is of importance in making these diagrams, an explanation of how reciprocal values may be easily laid off without calculation will be given.

Reciprocal Values Graphically Determined.—To avoid making the calculations and measurements as indicated above, the positions of the vertical lines representing the different pitch values may be determined graphically as follows:

First, determine the proper width of diagram as explained, then draw the two vertical lines representing the axis of y and the minimum pitch value to be considered. Now draw a horizontal line, as OA, Fig. 32. Commencing at intersection A lay on the vertical line to any convenient scale the pitch values to be considered—3 in. to 9 in. in the present case—using the intersection of the horizontal line with the vertical at A to represent the minimum pitch value—3 in. in this case. At O lay off vertically on the axis of y, to the same scale as used on the vertical line at A, a distance equal to the minimum pitch value—3 in. in this case, and connect the point thus obtained by a diagonal line AB with point A. The distance from the axis of y of any point of intersection on this diagonal line with a diagonal line drawn from any number on the vertical line at A through O, would represent the reciprocal of that number to the same scale that the distance from A to O represents the reciprocal of the minimum pitch value—3 in. in this case. The diagonal lines running from the numbers to O should be omitted in making an actual diagram because it is necessary only that the intersections be marked on the diagonal line AB. When the minimum number to be used is very small as compared with the maximum, the scale used in laying off the numbers on the vertical line at A should be made large to secure sharp intersections with the diagonal AB. It will be found more accurate in such cases to calculate the values of the reciprocals of the lowest numbers by the method given previously and measure the distances from the axis of y. It should be understood that O, as given in Fig. 32, has nothing to do with the origin, *i.e.*, where the zero efficiency line crosses the axis of y, as the position of the origin in that case is determined by the scale chosen to represent joint efficiencies, although it must lie on line OB.

Proof of Correctness of Graphical Method.—The following is the geometrical proof that the method of laying off reciprocals just described is correct. The proposition to be demonstrated is, if at A, Fig. 33, any vertical distance AB be laid off to represent a number h, and a horizontal line BO drawn, whose length represents $\frac{1}{h}$, to any scale, and at O a vertical OE is drawn equal to h, then if AB is extended to C the reciprocal of the number which would be represented by AC, or f, would be z, the dimension z, being the distance of the intersection of diagonals BE and CO from line OE.

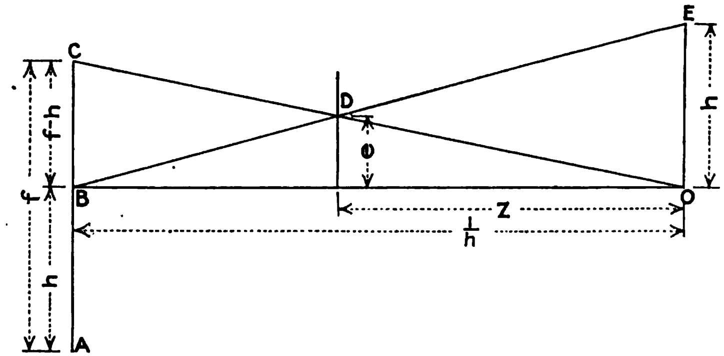


FIG. 33.

Since $AB = h$ and $AC = f$, then $BC = f - h$; and from the law of similar triangles $(f - h) : e = \frac{1}{h} : z$,

or,
$$\frac{e}{h} = zf - zh \qquad (1)$$

and
$$h : e = \frac{1}{h} : \left(\frac{1}{h} - z\right),$$

or,
$$\frac{e}{h} = 1 - zh \qquad (2)$$

From (1) and (2),

$zf - zh = 1 - zh$, or, $z = \frac{1}{f}$, which was to be proved.

Where f is less than h the proof would be as shown in Fig. 34, the lettering in this figure being the same as used in Fig. 33. From the law of similar triangles, $e:(h - f) = z:\frac{1}{h}$,

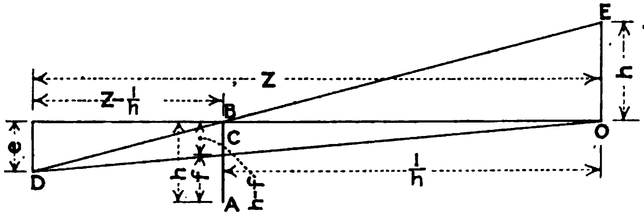


FIG. 34.

or,

$$\frac{e}{h} = zh - zf \tag{3}$$

and

$$e:h = \left(z - \frac{1}{h}\right):\frac{1}{h},$$

or,

$$\frac{e}{h} = zh - 1 \tag{4}$$

From formulas (3) and (4),

$zh - zf = zh - 1$, or, $z = \frac{1}{f}$, as before.

CHAPTER X

MAKING JOINT DIAGRAMS

The following explanation of how to construct diagrams giving the efficiency of riveted joints will be made without giving the reasons as to why the various steps are mathematically correct, and it is hoped that by means of this explanation one who is the least familiar with the diagrammatic representation of formulas will be able to draw diagrams to suit his own conditions, if the diagrams in this book do not answer.

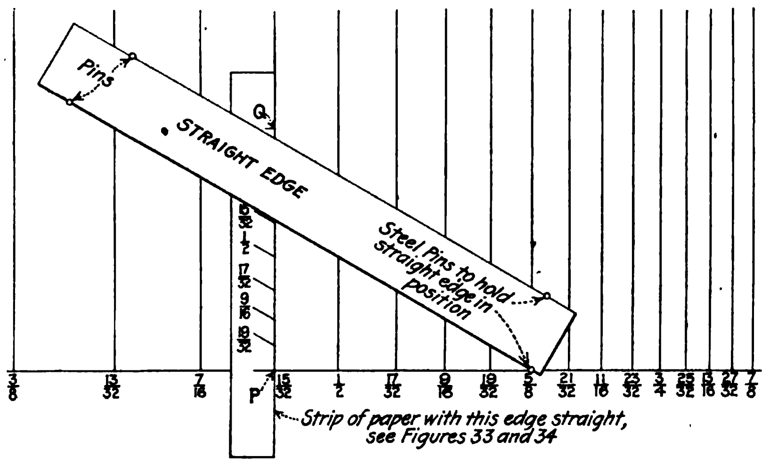


Fig. 35.—Use of reciprocal values of plate thickness.

Before commencing a diagram there should be prepared a series of sheets giving the reciprocal values of plate thicknesses. For the range of thicknesses used in making the diagrams shown in this book, ¼ in. to 1½ in., four sheets giving the reciprocal values of plate thicknesses were used, the range of thicknesses covered by each sheet being ¼ to 13/32 in., 17/32 to 1⅜ in., ¾ to 1½ in., and ⅜ to ⅞ in. These combinations of plate thicknesses may not be the best to follow but they well answered the purpose. All sheets were drawn to such a scale that the lines representing the end values were about 20 in. apart. The laying out of these sheets should be readily understood from the explanation given for laying off reciprocal values for rivet pitches (see Fig. 32). The object in using several sheets of reciprocal values for plate thicknesses is to secure accuracy, for a single sheet giving the reciprocal values for all the plate thicknesses to be considered, ¼ to 1½ in., could have been made to serve but the diagrams would not have been so accurate at the end representing the thicker plates, as will be evident when constructing the diagrams. For illustrating the use of the reciprocals of plate thicknesses, Fig. 35 shows the sheet prepared for the reciprocal values of plate thickness from ⅜ to ⅞ in. The sheet should be attached to a drawing board for convenience in using.

Making Diagrams for Lap-riveted Joints.—In making diagrams for lap joints a single diagram may be made to serve for single- and double-riveting without confusion, but triple-riveting could not be added because the lines representing plate thicknesses for this joint would run together with those of the double-riveted joints.

The first step in making a diagram is to determine the range of pitch values to be considered. For single- and double-riveted lap joints a range from 2 to 6 in. would cover all requirements for boiler seams hav-

ing $\frac{7}{8}$-in. rivet holes. Laying out the reciprocal values for pitch in accord with the method previously described and as illustrated in Fig. 36, where OB is the line from which the reciprocal values for pitch have been measured, proceed as follows: Place horizontal lines on the diagram to represent the joint efficiencies. That these lines should

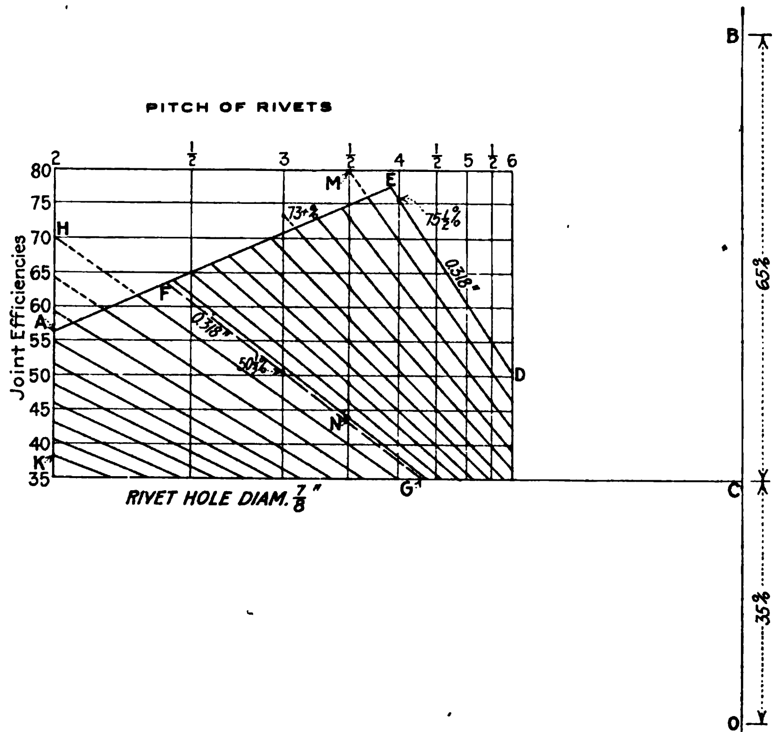


FIG. 36.—Diagram for lap joints and butt-strap joints with straps of equal width.

extend no further than they may be of service the maximum efficiency that may be required for the joint should be determined. As will be seen by reference to the equations for maximum joint efficiency, as given on page 150, the maximum efficiency of a double-riveted lap joint is $\frac{2C}{2C + T}$ or 77.5 per cent., where C is 95,000 lb. and T is 55,000 lb., therefore, the efficiency lines may be drawn to any convenient scale, as shown in Fig. 36, and need not extend beyond 80 per cent., to cover the range of efficiency values for double- (and therefore for single-) riveted lap joints. The lower line of the diagram may be made to represent 35 per cent., as it is not likely that values of efficiency lower than this will be required. Any scale may be used to represent the efficiency values but the scale chosen determines the distance apart of O and B, located at zero and 100 per cent. efficiency. If the scale of the drawing is large it is convenient to have the bottom line (35 per cent. in Fig. 36) near the bottom of the board. To get it there it is necessary to screw a piece of board on the bottom of the drawing board in line with OB, of such length that point O will lie on this extension; point B, should, of course, lie on the drawing board. The distance from C to O and C to B, in Fig. 36, should be 35 per cent. and 65 per cent., respectively, when laid off to the same scale as the efficiency lines. It is now necessary to decide on the size of the rivet hole, because a different diagram must be made for each rivet-hole diameter; it will be assumed that the diameter of the rivet hole under consideration is $\frac{7}{8}$ in.

The next step is the construction of the outline of the diagram, which for the double-riveted lap joint would be AE and ED, and for the single-riveted lap joint AF and FG.

The top line of the diagram passes through B, 100 per cent. above O, so that it is necessary to find only one other point on this line to draw it. The value of any point on this top line where it intersects a vertical line representing pitch of rivets in terms of efficiency, is the rivet-hole diameter divided by the pitch and the result subtracted from unity. Thus, at a point where line AE would intersect the vertical line representing 2-in. pitch, the efficiency would be $1 - \frac{\frac{7}{8}}{2} =$ 0.5625 or 56.25 per cent. Placing a straight edge against point B and

the point representing 56.25 per cent., on the 2-in. pitch line, the line *AE* is drawn. The position of the point on the 2-in. pitch line would be the same for single- or double-riveted lap joints, or for any type of joint with the same size rivet holes.

Next is the position of line *ED* which, if extended, would pass through *O*. In a manner similar to the drawing of the top line, it is necessary to secure only one other point on line *ED*, to draw it. The value in terms of efficiency for any intersection of line *ED* with a vertical line representing pitch is found by multiplying the crushing strength of the plate by the diameter of the rivet hole, and by the number of rivets in a unit section of the joint, dividing the result by the value of the pitch line multiplied by the tensile strength of the plate. Thus in Fig. 36 a point on line *ED*, which represents a double-riveted lap joint, where it intersects the pitch line representing 4 in., would be at

$$\frac{95{,}000 \times \frac{7}{8} \times 2}{4 \times 55{,}000} \times 100,$$

or 75.5 per cent.
Since this line also passes through *O*, it is necessary only to place a straightedge in line with these two points to draw *ED*. Since line *FG* represents a single-riveted lap joint, its intersection with the 3-in. pitch line, in terms of efficiency, would be

$$\frac{95{,}000 \times \frac{7}{8} \times 1}{3 \times 55{,}000} \times 100,$$

or 50.33 per cent. By drawing a line through this point and *O* as above, line *FG* is obtained. Lines *AE*, *ED*, *AF* and *FG* are the bounding lines of the diagrams for double- and single-riveted lap joints respectively, and no line representing the efficiency of such joints using ⅞-in. rivet holes will lie beyond these bounding lines. Line *FG* is drawn dotted to more readily indicate the boundary between the single- and double-riveting. All other lines required to complete the diagram pass through point *O*, and therefore it is necessary to find only one other point for any line to draw that line. The value in terms of efficiency of a point on any of these lines where they intersect the pitch lines is obtained by multiplying the number of rivets in a unit section by the square of the rivet-hole diameter, by the shearing strength of the rivet material in single shear, and by 0.7854, dividing the result by the pitch times the plate thickness and the tensile strength of the plate. Thus for a 7/16-in. plate and double-riveting, the efficiency value where the line representing this plate thickness would intersect the pitch line for 3 in., would be at

$$\frac{2 \times (\frac{7}{8})^2 \times 44{,}000 \times 0.7854}{3 \times \frac{7}{16} \times 55{,}000} \times 100,$$

or 73+ per cent. For a single-riveted joint with 2-in. pitch and the same plate thickness, the intersection would be at

$$\frac{1 \times (\frac{7}{8})^2 \times 44{,}000 \times 0.7854}{2 \times \frac{7}{16} \times 55{,}000} \times 100,$$

nearly 55 per cent. A point for each plate thickness might be determined in the same way for both single- and double-riveting, and lines drawn through such points to point *O* would complete the diagram, but there is a simpler and more accurate method that may be used, and it was for this purpose that the reciprocal values of plate thicknesses as illustrated in Fig. 35 were laid off.

That values for lines that would fall outside the bounding lines of the diagram will not be calculated, it is necessary to know the maximum plate thickness represented by line *ED* for double-riveted joints, and *FG* for single-riveted joints, as these lines represent all plate thicknesses from zero up to a maximum value for each rivet size. The maximum plate thickness represented by *ED* or *FG* is the same, and this thickness is equal to 0.7854 times the rivet-hole diameter times the shearing strength of the rivet material, divided by the crushing strength of the plate. For the diagram under consideration, the maximum plate thickness represented by either of these lines is

$$\frac{0.7854 \times \frac{7}{8} \times 44{,}000}{95{,}000} = 0.318 \text{ in.}$$

Laying off Lines by Means of Reciprocal Sheets.—After determining the maximum plate thickness represented by *ED*, as indicated above, the position of the intersection of the line representing the next higher fractional value of plate thickness with a pitch line should be calculated in the manner described above and the position of this intersection should be indicated on the pitch line by a dot. The pitch value chosen for making this calculation should preferably be one lying near *E* and to the left of this point. For example, in the diagram being drawn, the $3\frac{1}{2}$-in. pitch line would be a proper one to choose for double-riveting, and since the maximum value represented by line *ED*, as found above, is 0.318 in. or slightly more than $\frac{5}{16}$ in., the next higher fractional value for plate thickness, where increases by $\frac{1}{32}$ in. are to be considered, would be $\frac{11}{32}$ in. Calculating the value of the intersection of the line representing $\frac{11}{32}$-in. plate with the $3\frac{1}{2}$-in. pitch line for double riveting, would result as follows:

$$\frac{2 \times (\frac{7}{8})^2 \times 44{,}000 \times 0.7854}{3\frac{1}{2} \times \frac{11}{32} \times 55{,}000} \times 100,$$

or 80 per cent. and the position of this point is indicated at *M*, Fig. 36.

Next in order is the calculation of the value of the intersection of the line representing the thickest plate and the same pitch line of $3\frac{1}{2}$ in. Assuming that the thickest plate is to be $\frac{5}{8}$ in., the calculation would be as follows:

$$\frac{2 \times (\frac{7}{8})^2 \times 44{,}000 \times 0.7854}{3\frac{1}{2} \times \frac{5}{8} \times 55{,}000} \times 100,$$

or 43.9 per cent., as at *N*, Fig. 36. Next, secure a strip of stiff paper with one edge straight, as illustrated in Fig. 37, and place a line across it near the lower end at right angles to its straight edge, as at *P*, Fig. 37. Laying the strip on the $3\frac{1}{2}$-in. pitch line in Fig. 36, with the mark *P* coinciding with the point *N*, mark a point *Q* on the strip of paper opposite the point *M* on the diagram, so that the distance between *P* and *Q* on the strip will be the same as the distance between *M* and *N* in Fig. 36. The intersections of the lines representing intermediate plate thicknesses between $\frac{11}{32}$ in. and $\frac{5}{8}$ in. on the line representing $3\frac{1}{2}$-in. pitch may be obtained without further calculation by the aid of a sheet of reciprocal values of plate thicknesses similar to that given in Fig. 35, as follows: Place a pin at the point where the vertical line representing $\frac{5}{8}$-in. plate intersects the base line in Fig. 35 and also locate a pin on the line representing $\frac{11}{32}$-in. plate thickness (not illustrated in Fig. 35) at a point above the base line equal to the distance

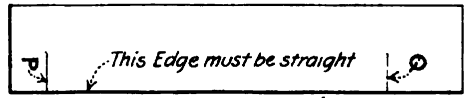


FIG. 37.

from *P* to *Q* on the strip of paper in Fig. 37. Next place a straightedge against these pins, as shown in Fig. 35; and place pins at the back of the straightedge to hold it in position. Place the straightedge of the paper against each of the vertical lines representing the different plate thicknesses between $\frac{11}{32}$ in. and $\frac{5}{8}$ in., with line *P*, Fig. 37, coinciding with the base line in Fig. 35, and mark a line on the paper at the under side of the straightedge after placing the paper in position against each of the lines representing plate thickness, as

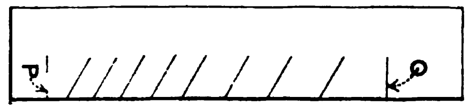


FIG. 38.

directed. When this operation has been completed the paper will appear as in Fig. 38. The position of the intersections drawn on the paper will give the position of the intersections of the lines representing the intermediate plate thicknesses between $\frac{11}{32}$ in. and $\frac{5}{8}$ in. with the $3\frac{1}{2}$-in. pitch line, *i.e.*, the intermediate points between *M* and *N* in Fig. 36. To complete the diagram place the strip of paper against the $3\frac{1}{2}$-in. pitch line in Fig. 36 and transfer the points on the paper to that pitch line between points *M* and *N* and draw lines across

the diagram through these points with the straightedge so placed that if the lines were extended they would pass through the point O. For the single-riveted portion of the diagram in Fig. 36, the position of the points H and K are determined as in the previous case, that is the value of the intersection H is

$$\frac{1 \times (7/8)^2 \times 44{,}000 \times 0.7854}{2 \times 11/32 \times 55{,}000} \times 100,$$

or 69.9 per cent., and K is

$$\frac{1 \times (7/8)^2 \times 44{,}000 \times 0.7854}{2 \times 5/8 \times 55{,}000} \times 100,$$

or 38.4 per cent. The 1 in the numerator is used in place of the 2 in the former calculation because there is only one rivet in shear in a unit section of a single-riveted joint; 2 is used in the denominator instead of 3½ as used in the calculation for the double-riveted joint because the pitch line for which the calculation is being made is 2 in. instead of 3½, as in the case of the double-riveted joint. A triple-riveted lap-joint diagram is the same as given above, except that it is necessary to take into consideration that there are three rivets in shear in a unit section of the joint instead of one or two. This must be provided for in locating the points corresponding to M, N, H and K in Fig. 36.

The making of diagrams for the single-, double- and triple-riveted butt joints with straps of equal width is the same as for the lap-riveted joints except that in finding the maximum value of plate thickness represented by lines corresponding to ED and FG in Fig. 36, the shearing value of the rivet material in double shear is used, and where this value is twice that in single shear, the maximum plate thickness represented by these lines for the butt-strap joints is twice that for the lap-riveted joints. In finding points corresponding to M and N of Fig. 36, the double shear of rivets is to be considered, and where the shearing value of the rivet material in double shear is taken as twice that in single shear, the same diagram will do for lap-riveted joints or butt-strap joints of the same riveting, by marking each line for the lap-riveted joints to represent double the plate thickness for butt-strap joints.

Formulas for Diagrams of Lap-riveted and Butt-strap Joints with Straps of Equal Widths.—See page 13 for notation.

The formulas giving the maximum efficiency for the different joints will be found on page 150, and these may be used to determine the maximum efficiency to be provided for in a diagram for any type of joint. While the preceding explanation as to how the different lines of a diagram may be laid out appears formidable on account of avoiding the use of formulas in that explanation, it will be seen by examining the formulas that follow, that the laying out of such diagrams is simple. While the formulas here given are simple, they would be more so if arranged on the assumption that the shearing strength of rivet material in double shear was twice that in single shear as has been used throughout this book, but this was not done because many engineers still use a different ratio between these values. With the formulas arranged as given, they serve equally well for any ratio between shearing strengths in double and single shear.

The top line of all diagrams passes through B, Fig. 36, and also any point where $E = 1 - \frac{d}{P}$. Limiting lines, ED or FG, Fig. 36, pass through point O, also any point where $E = \frac{NCd}{PT}$ for lap joints, and $E = \frac{N_2Cd}{PT}$ for butt-strap joints. Where N is the number of rivets in single shear and N_2 the number of rivets in double shear in a unit section of the joint; N_2 being taken as the number of rivets in one side of the joint only.

The value of N and N_2 is the same in lap and butt-strap joints with straps of equal width for the same kind of riveting, and a single letter could designate the number of rivets in a unit section of any of the joints of these types, but two letters are used to avoid confusion in the use of formulas for butt-strap joints with straps of unequal widths,

where it is necessary to distinguish between the rivets in single shear and those in double shear.

The limiting lines ED and FG, Fig. 36, represent maximum plate thickness values of

$$t = \frac{0.7854dS}{C}$$

for lap joints and

$$t = \frac{0.7854d(2S)}{C}$$

for butt-strap joints. The position of points such as M, N, H and K, Fig. 36, on any pitch line is determined by the formula

$$E = \frac{0.7854Nd^2S}{PtT}$$

for lap-riveted joints and

$$E = \frac{0.7854N_2d^2(2S)}{PtT}$$

for the butt-strap joints. The intersections of the pitch line with lines indicating plate thicknesses between those represented by the lines passing through points M and N or H and K (see Fig. 36) for all joints, may be found without calculation by means of the sheets giving the reciprocal values of plate thicknesses, as in Fig. 35, the use of which was explained in drawing the diagram, Fig. 36, see page 128.

CHAPTER XI

MAKING JOINT DIAGRAMS—(Continued)

DIAGRAMS FOR BUTT-STRAP JOINTS WITH STRAPS OF UNEQUAL WIDTHS

The diagrams for the double-, triple- and quadruple-riveted joints of this type are all of the same form, and directions for making a diagram for one will serve for all. Fig. 39, illustrates such a diagram the outlines for which are as given by lines AE, ED, FG, GK and GH. How to locate these bounding lines will be explained presently. The vertical pitch lines and horizontal efficiency lines are drawn as previously described.

Fig. 39 will be constructed for a quadruple-riveted joint with rivet holes, ⅞ in. in diameter and pitch values from 12 to 24 in. All lines of the diagram representing plate thicknesses if extended will pass through either points O or B on line OB. Therefore, if another point is obtained on any of these lines, they may be drawn.

Locating the Top Line AE.—The value of the intersection of the top line with any pitch line in terms of efficiency is found in the same way as for the diagrams previously drawn, *i.e.*, this value is equal to unity minus the fraction expressed by the diameter of the rivet hole divided by the pitch, or, for the 12-in. pitch line of Fig. 39, the intersection would be where the efficiency would equal $1 - \frac{7/8}{12} \times 100$ or 92.7 per cent. Locating this point on the 12-in. pitch line at A and placing a straight-edge so that a line may be drawn through this point and point B, line AE may be produced.

Locating Line ED.—The intersection of line ED with any pitch line it crosses is found in the same manner as for the previous joints considered, *i.e.*, by multiplying the crushing strength of the plate by the rivet-hole diameter and the number of rivets in a unit section of the joint, and dividing the value thus obtained by the pitch value times the tensile strength of the plate. Thus the point of intersection of ED with the 18-in. pitch line in Fig. 39 would be at

$$\frac{95{,}000 \times 7/8 \times 11}{18 \times 55{,}000} \times 100$$

or 92.4 per cent., since there are 11 rivets in a unit section of the joint. Drawing a line through this point and point O, will locate line ED.

Locating Line GK.—The next line to be drawn is GK. The point of intersection of this line and any pitch line is equal to the diameter of the rivet hole times the crushing strength of the plate times the sum of the products obtained by multiplying the number of rivets in double shear in a unit section of the joint by the shearing value in double shear, and the number of rivets in single shear, by the shearing strength of the material in single shear; the result divided by the pitch value times the shearing strength of the rivet material in double shear times the tensile strength of the plate material. Using the 16-in. pitch line in Fig. 39, the intersection of the line GK with it would, by the above calculation, be at a point where the efficiency equalled

$$\frac{7/8 \times 95{,}000\,(8 \times 88{,}000 + 3 \times 44{,}000)}{16 \times 88{,}000 \times 55{,}000} \times 100$$

or 89.74 per cent. for there are eight rivets in double shear and three in single shear in a unit section of a quadruple-riveted joint of this type,

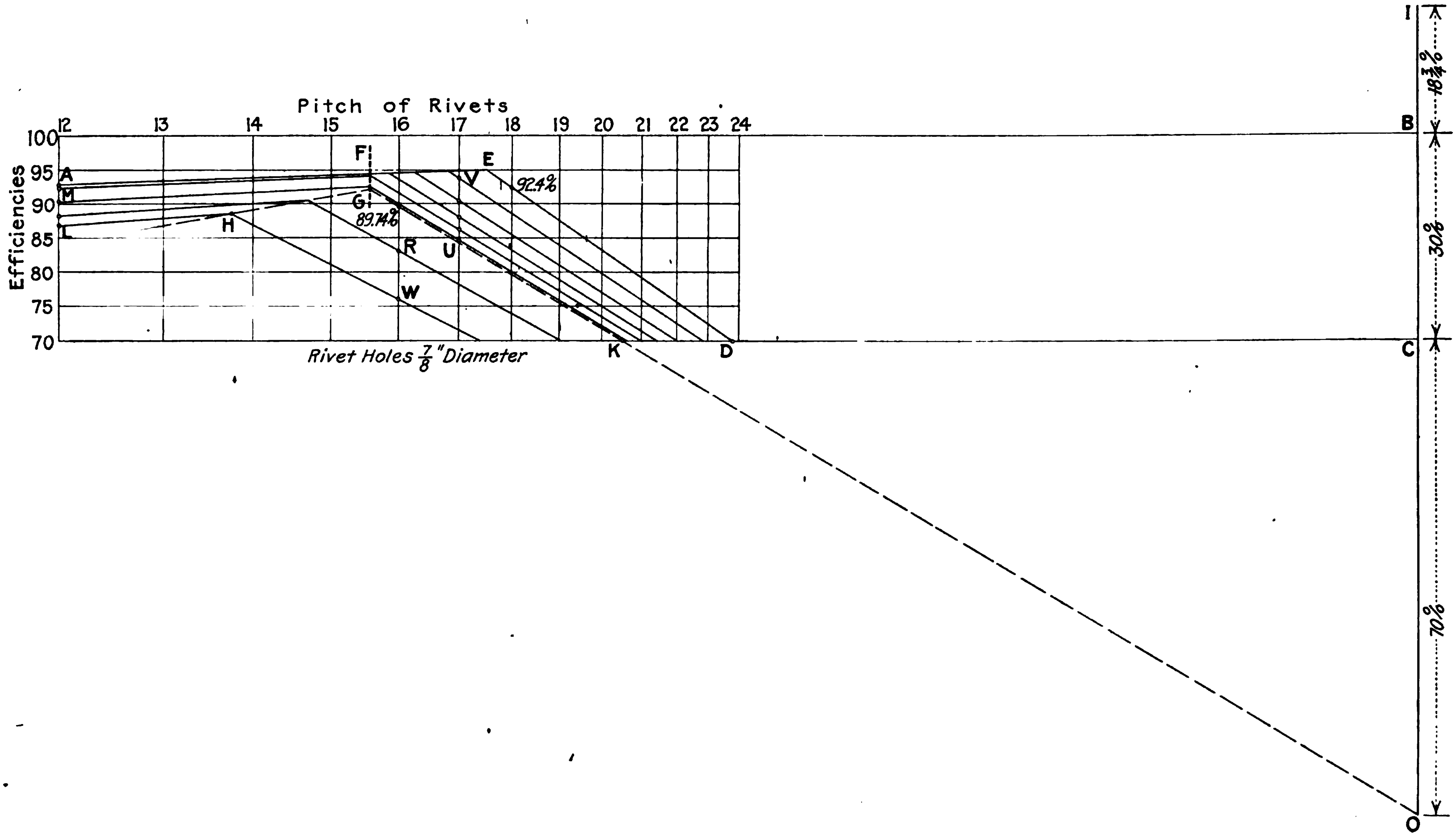


Fig. 39.—Diagram for butt-strap joints with straps of unequal width.

Locating the Line HG.—To locate the line *HG* it is best to obtain one point on it by finding the intersection of a line running to point *B* and one to point *O*, both of which represent the same plate thickness, preferably using the lines representing the thickest plate as indicated at *H*, Fig. 39. This intersection will represent one point on the line *HG*. It will be assumed that the thickest plate for which the diagram is constructed is ¾ in. To find the intersection of the line representing this thickness and the 12-in. pitch line (*L*, Fig. 39) subtract from 1 the value determined by multiplying the number of rivet pitches along the calking edge in a unit section times the diameter of the rivet hole divided by the pitch to be considered (12 in. in this case). Add to the result the value obtained by multiplying the number of rivets in single shear in a unit section by 0.7854 times the diameter of the rivet holes squared multiplied by the shearing strength of the rivet material in single shear, divided by the pitch times the thickness times the tensile strength of the plate. For a 12-in. pitch line and a ¾-in. plate with quadruple-riveting this value for efficiency would be

$$\left[\left(1 - \frac{4 \times \frac{7}{8}}{12}\right) + \frac{3 \times 0.7854 \times (\frac{7}{8})^2 \times 44{,}000}{12 \times \frac{3}{4} \times 55{,}000}\right] \times 100$$

or 86.86 per cent. as indicated at *L*, since in a quadruple-riveted joint there are four pitches of rivets along the calking edge of the outer butt strap in a unit section, and the number of rivets in single shear are three. To secure an efficiency point on line *HW*, as at *W* on the 16-in. pitch line, it is necessary to multiply 0.7854 times the diameter of the rivet hole squared times the sum of the products obtained by multiplying the number of rivets in double shear, by the shearing strength of the rivet material in double shear and the number of rivets in single shear by the shearing strength of the rivet material in single shear. The result as indicated above is to be divided by the pitch times the plate thickness times the tensile strength of the plate material. For point *W* on the 16-in. pitch line for ¾ in. plate the above calculation would be

$$\frac{0.7854 \times (\frac{7}{8})^2 \times [8 \times 88{,}000 + 3 \times 44{,}000]}{16 \times \frac{3}{4} \times 55{,}000} \times 100$$

or 76.2 per cent, since there are eight rivets in double shear and three in single shear in a unit section of a quadruple-riveted joint of this type.

Placing a straightedge on points *O* and *W* and drawing line *WH*, and on *L* and *B* and drawing *LH*, the intersection *H* is obtained. Another point on line *HG* is *I* on line *OB*. This point is above *O* in terms of efficiency at 1 plus the value of the fraction expressed by multiplying the number of rivets in single shear by the shearing strength of the material in single shear divided by the product of the number of rivets in double shear times the shearing strength of the rivet material in double shear. That is, point I, for quadruple-riveted joints with any diameter of rivet holes would be at a distance above *O* equal to

$$\left(1 + \frac{3 \times 44{,}000}{8 \times 88{,}000} \times 100\right)$$

or 118.75 per cent., as there are three rivets in single shear in a unit section of this joint.

Connecting points *I* and *H*, the line *HI* is obtained. It will be noted that the rivet-hole diameter is not a factor in locating point *I*, and the distance this point lies above *B* is the same for all the diagrams made for a single type of joint.

Locating Line FG.—Line *FG* is vertical, and the point *G* is at the intersection of the lines *GK* and *HG*, the positions of which have already been determined. This line may be laid off at once, but to test the accuracy of the lines already drawn it is best to calculate the position of line *FG* to prove that the intersection *G* is correct. The value of *FG* expressed as a pitch value is found by multiplying the diameter of the rivet hole by the number of rivet pitches along the calking edge in a unit section times the sum of the product obtained by multiplying the number of rows of rivets in double shear by the crushing strength of the plate material added to the tensile strength of the plate material and dividing the result by the tensile strength of the plate material. Thus, for a quadruple-riveted joint having four pitches along the calking edge in a unit section, and having two rows of rivets in double shear, the pitch for line *FG* would be

$$\frac{7/8 \times 4 \times (2 \times 95{,}000 + 55{,}000)}{55{,}000} = 15.59 \text{ in.}$$

By obtaining the proper reciprocal value to represent this pitch, as in laying off the pitch lines on the diagram, the position of line FG may be determined. As stated before, it should be at the intersection of lines GK and HG. The outline of the diagram has now been drawn, and to complete it place the lines representing the various plate thicknesses in the different sections.

Maximum Value of Plate Thickness Represented by Bounding Lines.—The positions of all the lines except two in each section of the diagram may be obtained by means of the sheets giving the reciprocal values of plate thickness, Fig. 35, by calculating only the end values. To calculate the values for the lines laying inside the bounding lines it is necessary to know the maximum values of plate thickness represented by these lines, as was explained in making the diagram for lap-riveted joints, that is, the maximum values represented by lines AE, ED and GK, Fig. 39, which are as follows:

Maximum Value of Plate Thickness by AE.—The maximum thickness represented by the line AE is determined by multiplying 0.7854, times the diameter of rivet holes times the shearing strength of rivet material when subjected to single shear, and dividing the result by the tensile strength of the plate, or, for AE, Fig. 39,

$$t = \frac{0.7854 \times 7/8 \times 44{,}000}{55{,}000} = 0.55 \text{ in.}$$

Maximum Value of Plate Thickness by ED.—The maximum plate thickness represented by this line is determined by multiplying 0.7854 by the diameter of the rivet holes and by the shearing strength of the rivet material when subjected to single shear, dividing the result by the crushing strength of the plate material. Thus, in the case of Fig. 39, the maximum plate thickness that would be represented by line ED would be

$$t = \frac{0.7854 \times 7/8 \times 44{,}000}{95{,}000} = 0.318 \text{ in.}$$

Plate Thickness by Line GK.—The plate thickness represented by this line, is twice the value of the maximum plate thickness represented by ED when the shearing strength of rivets in single shear is half that in double shear, and in other cases it may be determined by multiplying 0.7854 by the diameter of the rivet holes, by the shearing strength of the rivet material when subjected to double shear, dividing the result by the crushing strength of the plate. Thus the line GK, Fig. 39, would represent a plate thickness of

$$t = \frac{0.7854 \times 7/8 \times 88{,}000}{95{,}000} = 0.636 \text{ in.}$$

Line GK represents only one plate thickness.

Drawing Lines in Various Sections of Diagram.—With the limiting values for plate thicknesses represented by the bounding lines of the diagram calculated as described, the calculation of the end values for the lines in the different sections of the diagram may be proceeded with.

The intersection of any line under AF, and running in the same direction, with any pitch line, is found as previously explained in determining point L. For point M on the 12-in. pitch line, Fig. 39, which is to be on a line representing the next higher fractional value of plate thickness above 0.55 in. or 9/16 in., the operation would result as follows:

$$E = \left[\left(1 - \frac{4 \times 7/8}{12}\right) + \frac{3 \times 0.7854 \times (7/8)^2 \times 44{,}000}{12 \times 9/16 \times 55{,}000}\right] \times 100 \text{ or } 92.2 \text{ per cent.}$$

By laying off the distances from L to M on a sheet giving the reciprocals of plate thicknesses, see Fig. 35, as vertical distances above the base line on the line representing 9/16-in. plate thickness, the intermediate points of intersection of plate thickness between L and M may be secured.

Lines to the Left of GK.—Since line GK, Fig. 39, represents a plate thickness of 0.636 in., the next higher fractional value of plate thickness to be considered, if increments of 1/16 in. are taken, would be 11/16 in. The intersection of the line representing this thickness with the line representing 16-in. pitch is given as R, and the intersection of the

$\frac{3}{4}$-in. plate line with this same pitch line is given as W. The values of R and W in terms of efficiency would be determined by multiplying 0.7854 by the diameter of the rivet holes squared, by the sum of the products obtained by multiplying the number of rivets in double shear by the shearing strength of the rivet material in double shear, and the number of rivets in single shear, by the shearing strength of the rivet material in single shear, dividing the result by the pitch times the plate thickness times the tensile strength of the plate material. Thus, for $\frac{11}{16}$-in. plate the efficiency at R would be

$$\frac{0.7854 \times (\frac{7}{8})^2 \times [8 \times 88{,}000 + 3 \times 44{,}000]}{16 \times \frac{11}{16} \times 55{,}000} \times 100 \text{ or } 83.09 \text{ per cent.}$$

For $\frac{3}{4}$-in. plate the efficiency at W would be

$$\frac{0.7854 \times (\frac{7}{8})^2 \times [8 \times 88{,}000 + 3 \times 44{,}000]}{16 \times \frac{3}{4} \times 55{,}000} \times 100 \text{ or } 76.17 \text{ per cent.}$$

By using the sheet giving the reciprocal values of plate thickness as illustrated in Fig. 35, the intersections of any lines representing intermediate thicknesses between $\frac{11}{16}$ in. and $\frac{3}{4}$ in., with the pitch line for 16 in., could be determined without further calculation.

Lines to the Right of GK.—The values for the intersections of the lines to the right of GK, with pitch lines, are determined by multiplying the number of rivets in double shear in a unit section by the crushing strength of the plate, by the plate thickness, and by the rivet-hole diameter added to the product of the number of rivets in single shear times 0.7854, times the diameter of the rivet holes squared, times the shearing strength of the rivet material in single shear, and the whole result divided by the pitch times the plate thickness, times the tensile strength of the plate.

The maximum plate thickness represented by ED, is 0.318 in., and the thickness represented by GK is 0.636 in. The next higher and the next lower fractional values of plate thickness to be considered between these limits using $\frac{1}{16}$-in. increments, would be $\frac{3}{8}$ in. and $\frac{5}{8}$ in., respectively. The intersections of lines representing these plate values with the pitch line for 17 in., as indicated at V and U, Fig. 39, by the above method of calculation would be

$$\frac{8 \times 95{,}000 \times \frac{3}{8} \times \frac{7}{8} + 3 \times 0.7854 \times (\frac{7}{8})^2 \times 44{,}000}{17 \times \frac{3}{8} \times 55{,}000} \times 100 \text{ or } 93.76$$

per cent., for point V and

$$\frac{8 \times 95{,}000 \times \frac{5}{8} \times \frac{7}{8} + 3 \times 0.7854 \times (\frac{7}{8})^2 \times 44{,}000}{17 \times \frac{5}{8} \times 55{,}000} \times 100 \text{ or } 84.71$$

per cent., for point U.

By the same method as before described, the locations of the intersections of the lines representing intermediate plate values with the 17-in. pitch line may be determined without calculation by using the sheets giving the reciprocal values of plate thicknesses. From the following formulas, locating the different lines on the diagram is simple, although the above explanation given to avoid the use of formulas, appears complicated.

Formulas for Diagrams of Double-strap Butt Joints, with Straps of Unequal Widths.—In addition to the regular notation used to denote pitch of rivets, diameter of rivet holes, etc., as given on page 13, the following letters are used to designate other values:

Where e = number of rivet pitches along the calking edge of the outer butt strap in a unit section of a joint; two for double- and triple-riveting, four for quadruple-riveting and eight for quintuple-riveting.

n = number of rows of rivets in double shear; one for a double-riveted joint, two for triple-, quadruple- and quintuple-riveted joints.

N = number of rivets in single shear in a unit section of a joint; one for double- and triple-riveted joints, three for quadruple-riveting, and seven for quintuple-riveting.

N_2 = number of rivets in double shear in a unit section of a joint; two for double-riveting, four for triple-

riveting, eight for quadruple-riveting, and sixteen for quintuple-riveting.

Referring to Fig. 39, the top line of the diagram passes through point B, also any point where $E = 1 - \frac{d}{P}$.

Line ED passes through point O, also any point where

$$E = \frac{Cd(N_2 + N)}{PT}.$$

Line GK passes through point O, also any point where

$$E = \frac{dC[N_2(2S) + NS]}{PT(2S)}.$$

Line HG passes through point I, and the location of this point above O is where

$$E = 1 + \frac{NS}{N_2(2S)}.$$

Line HG also passes through any point as H, where lines under AF and GK, representing a single plate thickness, intersect. The formulas for obtaining the positions of these lines follow:

Line FG is at a pitch value determined by

$$P = \frac{ed(nC + T)}{T}.$$

Lines such as HW pass through point O and intersect the various pitch lines at points where

$$E = \frac{0.7854d^2[N_2(2S) + NS]}{PtT}.$$

Lines such as LH pass through point B and intersect the various pitch lines at points where

$$E = \left[1 - \frac{ed}{P}\right] + \frac{0.7854Nd^2S}{PtT}.$$

Lines in the section between GK and ED pass through point O and intersect any pitch line where

$$E = \frac{N_2Ctd + 0.7854Nd^2S}{PtT}.$$

Lines under ED that intersect line FG should intersect it at the same points that lines representing the same plate thickness under AF intersect FG.

Lines under GK should intersect line HG at the same points that lines representing the same plate thicknesses under AF intersect HG. Therefore it would be necessary to calculate only the positions of the lines under AF, and of such lines under ED as do not intersect FG, to complete a diagram, using the intersections of the lines under AF with lines FG and HG, to complete the lines under GK and ED. It will however, be best to make the calculations as explained, knowing that the intersections should come as indicated above serves to check the accuracy of the drawing.

Preparation of Sheets for Diagrams.—To lessen the labor in preparing sheets with the efficiency and pitch lines, it is practical to make a tracing of these lines, and by making a brown print negative of this tracing, blue or brown print positives may be made that will serve for making the diagrams. If the sheets are to be printed, care should be taken to have all positive prints made with the negative in one direction with respect to the length of the blue-print paper, because the shrinkage of the paper is not the same in each direction, and the sheets prepared for the diagrams will not all be of the same dimensions, unless the above precautions are observed. It is not necessary to include the line OB, Fig. 36, on the tracing as the position of this line may be determined after the sheet is placed on the drawing board. Since there is considerable shrinkage of the paper in printing, the distance required between the line OB and the first pitch line representing the largest pitch value, will not be the same as for the original tracing. However, this does not matter, for by measuring the distance between the extreme vertical lines on the print and using this measure

to represent W in the formula $y = \frac{aW}{m - a}$ as given on page 122, the correct distance between OB and the first pitch line can be readily determined.

It is necessary to allow for shrinkage of the blue-print paper in locating the position of points O and B, Fig. 36, with respect to the bottom line of the print, *i.e.*, the distances CO and CB should be laid off to the same scale of efficiencies as represented by the efficiency lines on the prints, and not to the scale to which the original tracing may have been drawn.

CHAPTER XII

RIVETED JOINTS OF MAXIMUM EFFICIENCY

The following is to show how joints of maximum efficiency of any type may be designed, how the highest efficiency joint with the usual symetrical arrangement of rivets may be laid out, and why the efficiency of these latter joints is not usually equal to the efficiency of joints of maximum efficiency having the same number of rows of rivets. This requires an explanation of the underlying principles of joint design. It should be understood that where the diagrams in this book apply it is best to consult the diagrams, which will show not only the arrangement for the highest efficiency but directly indicate the efficiency of all practical arrangements of rivets for the type of joint under consideration.

NOTATION

For convenience in reference the following notation is here given, being the same as used in other parts of the book:

Where n = number of rows of evenly spaced rivets in a joint.
m = number of rows of unevenly spaced rivets.
P = distance between the centers of rivets or pitch in inches.
t = plate thickness in inches.
t_1 = thickness of the straps in inches.
d = driven diameter of the rivet, that is, the diameter of the rivet hole.
C = crushing strength of the plate or straps in pounds per square inch.
T = tensile strength of the plate in pounds per square inch.
S = shearing strength of the rivet material in pounds per square inch when subjected to single shear.
$2S$ = shearing strength of the rivet material in pounds per square inch when subjected to double shear.
R = number of rivets in a unit section of a joint, *i.e.*, the number of rivets in one side of a joint in the case of butt-strap joints.
E = joint efficiency.

Maximum-efficiency Joints Having a Single Row of Rivets.—The formulas giving the efficiency of a butt-strap joint of this type are:

$$E = \frac{(P - d)tT}{PtT} \text{ or } E = 1 - \frac{d}{P} \qquad (1)$$

for the breaking of the net section of the plate between the rivet holes. For crushing of the plate in front of the rivets

$$E = \frac{Ctd}{PtT} \text{ or } E = \frac{Cd}{PT} \qquad (2)$$

For the shearing of rivets

$$E = \frac{0.7854d^2(2S)}{PtT} \qquad (3)$$

Since in any joint the values of T, C, $2S$ and d will be constant, formulas (1), (2) and (3) may be written for convenience in considering them as follows:

$$E = 1 - \frac{a}{P} \qquad (4)$$

$$E = \frac{b}{P} \qquad (5)$$

and

$$E = \frac{e}{Pt} \tag{6}$$

where a, b and e represent the values or combined values of the constant factors used in formulas (1), (2) and (3).

By comparing formulas (5) and (6) it is seen that they would be of the same value where $t = \frac{e}{b}$, and it is evident that for increasing values of t beyond this point, the value of equation (6) would be less than equation (5), and conversely, for decreasing values of t equation (6) would be of greater value than (5), therefore, the efficiency of the joint as determined by (5) would be the true joint efficiency for all values of t less than $t = \frac{e}{b}$, as far as the two methods of failure given by (5) and (6) are concerned. Comparing equations (4) and (5), it is evident that the value of (4) increases with increasing values of P, and approaches unity or 100 per cent., as the value of P approaches infinity, also that the value of (5) decreases with increases in the value of P, approaching zero as a limit as P approaches infinity. Since (4) increases and (5) decreases with increasing values of P, and conversely for decreasing values of P, at some value of P, (4) and (5) become equal to each other. The efficiency at this point is the highest that can be reached by the consideration of the two methods of failure indicated by (4) and (5), for any change due to either an increase or decrease in the value of P at this point will result in a lower efficiency by either (4) or (5). From the above comparisons of formulas (5) and (6), and (4) and (5), it is evident that the efficiency of a joint where (4) and (5) become equal, is the highest that can be reached for the joint under consideration, if the value of t is not more than $t = \frac{e}{b}$, for it has been shown that at this value of t, the efficiency by either (5) or (6) was alike and for all values of t less than $t = \frac{e}{b}$, formula (5) would indicate the true efficiency.

Plate Thickness and Rivet Diameter for Maximum Efficiency.—The explanation given shows that all that is required to design a single-riveted joint of maximum efficiency is to see that the plate thickness is not more than $t = \frac{e}{b}$, or substituting the proper values for e and b, in that equation

$$t = < \frac{0.7854d(2S)}{C} \tag{7}$$

for butt and double-strap joints, where the straps are of equal widths, and

$$t = < \frac{0.7854dS}{C} \tag{7a}$$

for lap joints, butt joints using a single strap, or where the straps are of unequal widths.

By transposition in the above formulas the rivet diameter required is seen to be

$$d = > \frac{tC}{0.7854(2S)} \tag{8}$$

for butt and double-strap joints where the straps are of equal widths, and

$$d = > \frac{tC}{0.7854S} \tag{8a}$$

for lap joints or for butt joints using a single strap or where the straps are of unequal widths. Using the proper plate thickness, a maximum efficiency joint may be designed by spacing the rivets at such a distance that the efficiency as determined by either equations (1) or (2) would be equal. For maximum efficiency, for single-riveting the following pitch must be used:

$$1 - \frac{d}{P} = \frac{Cd}{PT} \text{ or } P = d\left(\frac{C}{T} + 1\right) \tag{9}$$

For example, if it is desired to design a single-riveted joint of maximum efficiency where $C = 95{,}000$ lb. and $T = 55{,}000$ lb., and $(2S) = 88{,}000$ lb., by using formula (9) the pitch required would be $P = 2.7273d$. If the plate thickness to be used was ½ in., the rivet-hole diameter would have to be, from formula (8),

$$d = \frac{0.5 \times 95{,}000}{0.7854 \times 88{,}000} = 0.688 \text{ in. or more.}$$

If ¾-in. rivet holes were selected, the pitch required would be $2.7273 \times \frac{3}{4} = 2.045$ in. The efficiency of such a joint would, of course, be determined by dividing the length of the net section of the plate between the rivet holes by the pitch, but it will be remembered that the efficiency was also determined by the point where formulas (1) and (2) crossed. Since the pitch as given by formula (9) represents the efficiency at this point, if the value of P as determined by formula (9) is substituted in either equation (1) or (2), the resulting efficiency will be that for a joint of maximum efficiency; thus

$$E = \frac{C}{C + T} \tag{10}$$

Formula (10) is a general formula for the efficiency of a joint of maximum efficiency. To make it applicable to any joint place before C in both the numerator and denominator a coefficient equal to the number of rivets in a unit section of the joint. The coefficient in the case of a single-riveted joint is unity.

Maximum-efficiency Joints Having More Than a Single Row of Rivets.—As has been shown in deriving formula (9), the design of a single-riveted joint of maximum efficiency depends on having the tensile strength of the net section of the plate between the rivet holes equal the crushing strength of the plate in front of the rivets for certain relations between the plate thickness and rivet diameter. Therefore, if two rows of rivets are to be used for a joint of maximum efficiency, the pitch of rivets would have to be $(P' - d)$ greater than for a single-riveted joint. The pitch for two rows of rivets in a joint of maximum efficiency would be $d + 2\,(P' - d)$; for three rows the pitch would be, $d + 3(P' - d)$, and for n rows would be $d + n(P' - d)$, where P', represents the pitch for a single-riveted joint of maximum efficiency. Substituting in the above expression the value of P' as given in formula (9) for the pitch of rivets in a joint of maximum efficiency using n evenly spaced rows of rivets, the result is

$$P = d\left(\frac{C}{T}n + 1\right) \tag{11}$$

The efficiency of such a joint must equal the pitch less the rivet-hole diameter divided by the pitch, or for n rows the efficiency would be

$$\frac{\frac{C}{T}dn + d - d}{\frac{C}{T}dn + d} \text{ or } E = \frac{nC}{nC + T}$$

which is the same as the general formula for the efficiency of a joint of maximum efficiency since n is the number of rivets in a unit section

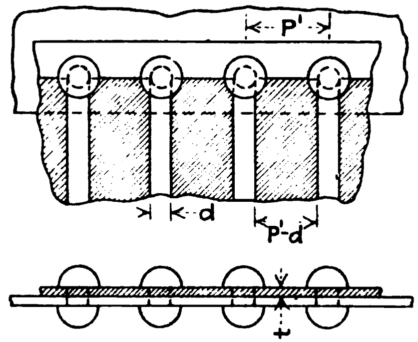


Fig. 40.

of the joint. See formula (10). The efficiency of a joint designed in this way may be made to approach 100 per cent. as nearly as desired, for there is no limit to the number of rows of rivets that may be used.

However, higher-efficiency joints for a given number of rows of rivets may be designed by arranging the rivets so that they will be spaced differently in each succeeding row. Figs. 40, 41, and 42 show graphically how joints with evenly spaced rivets may be designed, the net section of the plate between the rivet holes in such joints increasing by the amount $(P' - d)$ with each additional row of rivets used. The pitch is the same in each row. It will be noted that there is a strip of plate of $(P' - d)$ width, to care for each rivet in the joint.

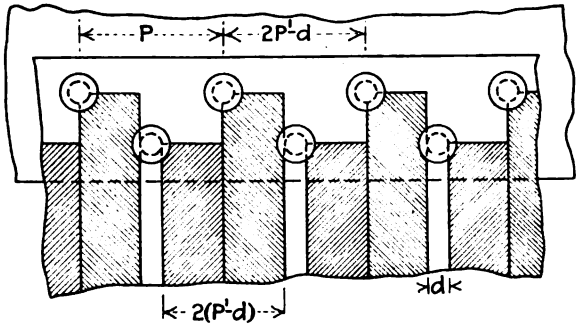


Fig. 41.

Joints with Constantly Widening Pitches.—By examining, Fig. 40, and remembering that the tensile strength of the plate between the rivet holes in a single-riveted joint of maximum efficiency must equal the crushing strength of the plate in front of a rivet, it is evident that the unshaded portion of the plate in front of the rivets, of width d might be omitted without effecting the strength of the joint. Also that rivets in a second row might be added, without using any of the plate required to transmit stress to the rivets in the first row, if enough of these unshaded sections of width d were employed equal to a pitch of the rivets on the first row. Thus, if P' represented the pitch of rivets on the first row, where the rivets were arranged for a joint of maximum efficiency on that row, the pitch of rivets on the second row would be $\frac{P'}{d}$ times the pitch of the first row or $P = \frac{P'}{d}P'$. But from formula (9) it is seen that $\frac{P'}{d}$ is equal to $\frac{C}{T} + 1$; therefore, the pitch of rivets on the second row would be

$$P = P'\left(\frac{C}{T} + 1\right).$$

If a third row of rivets were to be added, the pitch required for maximum efficiency would be $\frac{P'}{d}$ times the pitch of the preceding row

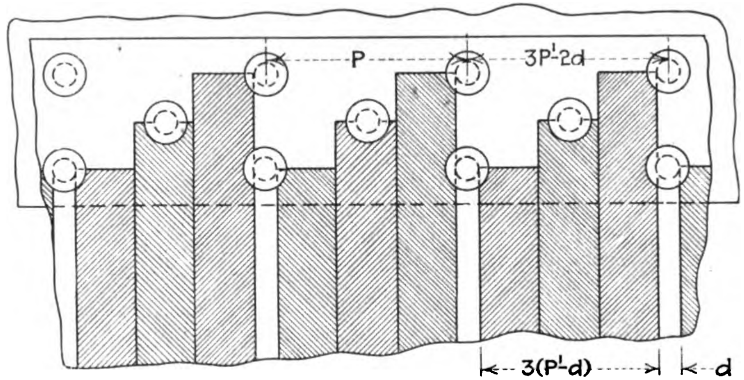


Fig. 42.

or $\frac{P'}{d} \times P'\left(\frac{C}{T} + 1\right)$ or $P'\left(\frac{C}{T} + 1\right)^2$, since $\frac{P'}{d}$ is equal to $\frac{C}{T} + 1$. For a joint of m rows of rivets, the pitch would be $P = P'\left(\frac{C}{T} + 1\right)^{m-1}$, or, since the value of P' from formula (9) is $\frac{C}{T}d + d$, the pitch of the outer row of rivets in a joint of m rows is

$$P = \left(\frac{C}{T}d + d\right)\left(\frac{C}{T} + 1\right)^{m-1} \text{ or } P = d\left(\frac{C}{T} + 1\right)^m \qquad (12)$$

Mixed Pitches.—If instead of having the pitches widened from row to row, mixed pitches were used, *i.e.*, any given number of rows of

evenly spaced rivets applied to form the inner rows, and the pitches then to be widened out from row to row, a joint of maximum efficiency of this type would be designed as follows: The primary pitch or pitch of rivets on the inner rows would be that determined by formula (11) and the pitch of the rivets in the outer rows after the addition of m rows with constantly widening pitches would be

$$P = d\left(\frac{C}{T}n + 1\right)\left(\frac{C}{T} + 1\right)^m \tag{13}$$

The exponent of the last factor in formula (13) is m and not $(m - 1)$, as was the case in deriving formula (12), for in that case m represented all the rows including the initial row, while in this case the initial row is included with the evenly spaced rows.

Number of Rivets in a Unit Section of Joint.—The number of rivets in a unit section of a joint of maximum efficiency, from the method of deriving the pitch for such joints, will be the pitch less the rivet-hole diameter divided by $\frac{C}{T}d$; *i.e.*, divided by the length of the net section of the plate between the rivet holes in a single-riveted joint of maximum efficiency (see formula (9). The number of rivets in a unit section of a joint where the pitches are uniform in each row, since the pitch $P = \frac{C}{T}dn + d$ (see (11)) would be

$$R = \frac{\frac{C}{T}dn + d - d}{\frac{C}{T}d} \text{ or } R = n \tag{14}$$

The number of rivets in a unit section of a joint with constantly widening pitches would be (see formula (12))

$$R = \frac{d\left(\frac{C}{T} + 1\right)^m - d}{\frac{C}{T}d} \text{ or } R = \frac{\left(\frac{C}{T} + 1\right)^m - 1}{\frac{C}{T}} \tag{15}$$

The number of rivets in a unit section of a joint of maximum efficiency, where mixed pitches are used, would be (see formula (13))

$$R = \frac{d\left[\left(\frac{C}{T}n + 1\right)\left(\frac{C}{T} + 1\right)^m - d\right]}{\frac{C}{T}d}$$

or

$$R = \frac{\left(\frac{C}{T}n + 1\right)\left(\frac{C}{T} + 1\right)^m - 1}{\frac{C}{T}} \tag{16}$$

Efficiencies of Joints.—The efficiency of any of the three types of maximum-efficiency joints just given may be determined by formula (10), that is,

$$E = \frac{RC}{RC + T} \tag{17}$$

in which R represents the number of rivets in a unit section of the joint of n rows of evenly spaced rivets, or in m rows of unevenly spaced rivets, or in a combination of even and uneven spacing. That this is so may also be shown by dividing the length of the net section of the plate between the rivet holes in an outer row by the pitch of the rivets in that row, which gives the efficiency of a joint designed for maximum efficiency. By seeing that the relation between the rivet diameter and the plate thickness complies with formulas (7), (7*a*), (8) or (8*a*), as the case may require, it is possible by means of formulas (11), (12) and (13) to know exactly what the pitch will be in the last row of a joint of maximum efficiency of either of the three types thus far discussed. From the values determined by formulas (14), (15) and (16) and used in formula (17), the efficiency of any joint of these three types may be indicated at once.

Symmetrical Spacing of Rivets.—It will be noted that by using formula (12) in obtaining the value for pitch in any two adjacent rows of rivets, that the pitch of one row will not be an even multiple of the

pitches in the adjacent row unless $\frac{C}{T}$ is a whole number. It is on this account that a maximum-efficiency joint cannot be usually obtained with symmetrically spaced rivets in each row, for the ratio $\frac{C}{T}$ is not usually a whole number. If C was 100,000 lb. and T 50,000 lb., then

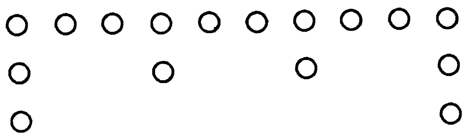


FIG. 43.—Symmetrical arrangement of rivets in different rows.

$\frac{C}{T}$ would be two, and $d\left(\frac{C}{T}+1\right)^m$ would be $d(3)^m$, and the rivets in each succeeding row of a joint of maximum efficiency would be arranged as shown in Fig. 43 in which the pitch of the rivets in the second row is equal to three pitches of the first row, and the pitch of the third row is equal to three pitches of the second row, and so on. Since the

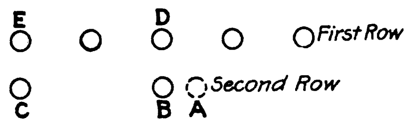


FIG. 44.

ratio $\frac{C}{T}$ is not usually a whole number, and as it is most desirable to have the rivets in each succeeding row arranged symmetrically, instead of spacing to give maximum efficiency, the best efficiency that may be obtained and still have the spacing symmetrical and suitable for driving and calking is used.

If in Fig. 44, A to C represented the pitch on the second row of rivets where the spacing was arranged for maximum efficiency, as would be the case where $\frac{C}{T} = 1.5$, and it was decided to make the spacing symmetrical by moving the rivet at A to position B, the efficiency of the joint would be considerably impaired because the outer net section of the plate between the rivet holes C and B would be weakened. The efficiency might be improved without affecting the symmetry of the rivet spacing, by stretching out the pitch in both rows. The best arrangement for efficiency is had when the distance from C to B is such that the crushing strength of the plate in front of the rivets in a unit section equals the tensile strength of the plate between the rivet holes C and B. The length of the net section of plate between rivet holes is $\frac{C}{T}d$ when the strength of the plate in front of the rivets to resist crushing equals the strength of this net section to resist a tensile strain, (equate formulas (1) and (2)). To care for three rivets in a unit section, as shown in Fig. 44, the net section length from C to B would be $3\frac{C}{T}d$, or the pitch from C to B would be $3\frac{C}{T}d + d$. By adding other rows of rivets in the same manner keeping the outer net section of such length that its strength will equal the crushing strength of the plate in front of the rivets, the pitch of the rivets in the different rows will constantly change with the addition of each row of rivets.

Joints with Symmetrically Spaced Rivets.—To properly arrange formulas to represent the pitch for any number of rows of rivets where the spacing of the rivets in the different rows is to be symmetrical, let r represent the next whole number below $\left(\frac{C}{T}+1\right)$. In Fig. 44, r would be 2. The number of pitches of one row that go to make up the next outer row will be r pitches. Starting with the outer row of a joint with m rows of rivets, a unit section of the joint would contain one rivet in the outer row, r rivets in the next inner row, and r^2 rivets on the third row, and the total number of rivets in a unit section of m rows would be the sum of the geometrical series, $1 + r + r^2 + r^3 + \ldots\ldots r^{m-1}$.

The sum of such a series is $\frac{r^m - 1}{r - 1}$. Therefore this would be the number of rivets in a unit section of the joint, or

$$R = \frac{r^m - 1}{r - 1} \tag{18}$$

Since the pitch of the rivets in the outer row is to be such that the number of rivets times $\frac{C}{T}d$ plus the diameter of a rivet hole must equal this pitch, the pitch would be

$$P = \left(\frac{r^m - 1}{r - 1}\right)\frac{C}{T}d + d \text{ or } P = d\left[\left(\frac{r^m - 1}{r - 1}\right)\frac{C}{T} + 1\right] \tag{19}$$

By the method of arranging the rivet for the above joint it is evident the efficiency will be found in the same way as for a joint of maximum efficiency, that is,

$$E = \frac{RC}{RC + T} \tag{20}$$

Mixed Pitches.—Where mixed pitches are used, the number of rivets in a unit section on a row of the evenly spaced rivets is r^m, where m is the number of rows of rivets of widening pitches. Therefore, nr^m will be the total number of rivets in a unit section in the evenly spaced rows, where n is the number of rows of evenly spaced rivets. The number of rivets in a unit section of the joint in the rows with widening pitches will be $\frac{r^m - 1}{r - 1}$ as before; therefore, the total number of rivets in a unit section of a joint of n rows of evenly spaced rivets, and m rows of unevenly spaced rivets will be

$$R = \frac{r^m - 1}{r - 1} + nr^m \tag{21}$$

Since the net section of the plate between the rivet holes in the outer row must be equal to the number of rivets in a unit section times $\frac{C}{T}d$, the pitch of the outer row will be

$$R\frac{C}{T}d + d \text{ or } \left(\frac{r^m - 1}{r - 1} + nr^m\right)\frac{C}{T}d + d$$

That is,

$$P = d\left[\left(\frac{r^m - 1}{r - 1} + nr^m\right)\frac{C}{T} + 1\right] \tag{22}$$

Efficiency of Joint.—It will be remembered that the pitch of the inner row of rivets where the pitch was arranged for a joint of maximum efficiency was widened to make the pitch in the succeeding rows such that the strength of the net section of the plate in the outer row equal to the crushing strength of the plate in front of all the rivets in a unit section. Therefore, the failure of a joint designed in this manner cannot be by the breaking of any of the inner net sections. The efficiency will be determined by the number of rivets in a unit section times the crushing strength of the plate in front of a rivet divided by the strength of a section of the solid plate equal to the pitch. The efficiency of such a joint of n rows of evenly spaced rivets and m rows of unevenly spaced rivets will be

$$E = \frac{R\left(\frac{C}{T}d\right)}{R\left(\frac{C}{T}d\right) + d}$$

in which R is the number of rivets in a unit section of the joint.

Expressed algebraically this becomes:

$$E = \frac{\left[\frac{r^m - 1}{r - 1} + nr^m\right]\frac{C}{T}d}{\left[\frac{r^m - 1}{r - 1} + nr^m\right]\frac{C}{T}d + d} \text{ or } \frac{C\left[\frac{r^m - 1}{r - 1} + nr^m\right]}{C\left[\frac{r^m - 1}{r - 1} + nr^m\right] + T}$$

The expression in the brackets is the number of rivets in a unit section of the joint, see formula (21); therefore, the efficiency of such a joint will be found in the same way as for a joint of maximum efficiency, that is, the efficiency is

$$E = \frac{RC}{RC + T} \tag{23}$$

Symmetrical Spacing where Pitches are Increased.—If, as in Fig. 45, the spacing of the rivets had been made symmetrical by placing the rivet at A in position B, in line with rivet F in the first row, instead of in line with rivet D in the first row, a slight improvement in the efficiency over that obtained by the first method of producing symmetry would be secured under certain conditions: It is evident from Fig. 45 that if rivet A is moved to B without changing the spacing of the rivets

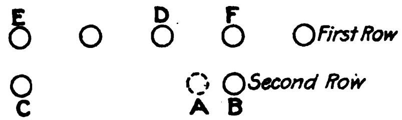


FIG. 45.

in the inner row, failure cannot occur by the breaking of the outer net section between the rivet holes. Since the plate sections between the rivet holes in the inner row have been arranged so that they are as strong as the rivets, failure will be by crushing of the plate in front of the rivets in the outer row, and crushing of the plate or breaking of the net section between the rivet holes in the inner row. Closing up of the rivets in both rows will weaken the joint because this would tend to

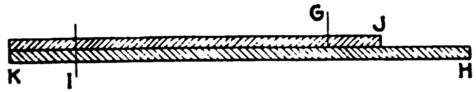


FIG. 46.

lessen the net section strength between the rivet holes in the first row more proportionately than it would the strength of the solid plate, thereby reducing the ratio expressing the joint efficiency. That this is so is seen from Fig. 46. Let the distance from K to H represent the length of a pitch of rivets from C to B in Fig. 45, and let K to G represent the length of the sum of the net sections between the rivet holes of the first row from E to F, and let G to J represent the length of plate of equivalent tensile strength to the crushing strength of the plate in front of a rivet, or the length of one net section of the inner row. Then the efficiency of the joint as shown in Fig. 45 will equal $\frac{K \text{ to } J}{K \text{ to } H}$ in Fig. 46. If the rivets were moved closer together, the effect would be the same as cutting off the section K to I in Fig. 46. The ratio $\frac{I \text{ to } J}{I \text{ to } H}$ would be less than $\frac{K \text{ to } J}{K \text{ to } H}$, and since these ratios express the joint efficiency under the two assumed conditions, the higher efficiency will be obtained by not shortening the distance. Spreading the rivets further apart than from E to F, Fig. 45, will lessen the efficiency because there are no more rivets added to a unit section, and as the strength of the solid plate of a length equalling the pitch is increased by widening the pitch, the ratio of the crushing strength of the plate in front of all the rivets in a unit section divided by the strength of the solid plate, is lowered. Therefore, the joint efficiency would be less.

Strongest Joint Using Symmetrical Arrangement of Rivets.—If r_1 represents the next whole number above $\left(\frac{C}{T} + 1\right)$ the pitch of the rivets on the first row would be $P = \frac{C}{T}d + d$; for the second row $P = r_1\left(\frac{C}{T}d + d\right)$; for the third row $P = r_1^2\left(\frac{C}{T}d + d\right)$; and for m rows

$$P = r_1^{m-1}d\left(\frac{C}{T} + 1\right) \tag{24}$$

Since the efficiency of a joint with the rivets symmetrically spaced as described is equal to the crushing strength of the plate in front of all the rivets in a unit section divided by the strength of the solid plate, the efficiency will be $\frac{RCd}{PT}$. And as the number of rivets in a unit section is

$$R = \frac{r_1^m - 1}{r_1 - 1} \tag{25}$$

and the pitch is $P = r_1^{m-1}d\left(\frac{C}{T} + 1\right)$ the efficiency will be

$$E = \frac{\left(\frac{r_1^m - 1}{r_1 - 1}\right)Cd}{r_1^{m-1}d\left(\frac{C}{T} + 1\right)T} \text{ or } \frac{\left(\frac{r_1^m - 1}{r_1 - 1}\right)C}{Cr_1^{m-1} + Tr_1^{m-1}}$$

As $\frac{r_1^m - 1}{r_1 - 1}$ is the total number of rivets in a unit section of the joint, and r_1^{m-1} is the number of rivets in the inner row of rivets included in a unit section length, the efficiency is

$$E = \frac{RC}{R_aC + R_aT} \tag{26}$$

where R_a is the number of rivets on the inner row in a length equal to the pitch of the outer row of rivets.

Symmetrical Arrangement of Rivets with Mixed Pitches.—In the case of mixed pitches for the type of joint under discussion, the pitch of the rivets on the evenly spaced rows will be $P = \frac{C}{T}dn + d$, as for maximum efficiency, where the rivets in each row are spaced alike. The pitch of the first row of widened pitch will be $P = r_1\left(\frac{C}{T}dn + d\right)$, and for the second row of widened pitch the first factor will be r_1^2, and for the third, r_1^3, and so on. For n rows of evenly spaced rivets and m rows of unevenly spaced rivets, the pitch will be

$$P = r_1^m d\left(\frac{C}{T}n + 1\right) \tag{27}$$

The number of rivets in a unit section length of the joint in the rows of widening pitches is $R = \frac{r_1^m - 1}{r_1 - 1}$ as before, and the number of rivets in a unit section length in a row of the evenly spaced rivets is r_1^m. Therefore, the number of rivets in a unit section length of n such rows would be nr_1^m, and the total number of rivets in a unit section length of such a joint would be

$$R = \frac{r_1^m - 1}{r_1 - 1} + nr_1^m \tag{28}$$

The efficiency of this joint is equal to the number of rivets in a unit section length times Cd, divided by the pitch times T, that is,

$$E = \frac{Cd\left[\frac{r_1^m - 1}{r_1 - 1} + nr_1^m\right]}{Tr_1^m\left(\frac{C}{T}dn + d\right)} \text{ or } \frac{C\left[\frac{r_1^m - 1}{r_1 - 1} + nr^m\right]}{nr_1^mC + r_1^mT}$$

The expression included in the brackets in the numerator is the total number of rivets in a unit section length of the joint, and the coefficient of C in the denominator is the number of rivets in all of the evenly spaced rows of rivets. The coefficient of T in the denominator is the number of rivets in a single row of the evenly spaced rivets in a unit section which will be designated as R_b, therefore, the highest efficiency attainable in a joint where r_1 is the next whole number above $\left(\frac{C}{T} + 1\right)$ may be written

$$E = \frac{RC}{nR_bC + R_bC} \tag{29}$$

When r or r_1 must be used for Highest Efficiency.—Where pitches are constantly widened from row to row and symmetrical spacing is obtained by making the increase in the pitch from row to row equal r, the next whole number below $\left(\frac{C}{T} + 1\right)$, or by making the increase in pitch from row to row r_1 the next whole number above $\left(\frac{C}{T} + 1\right)$, it is evident that both methods of obtaining symmetry cannot produce equal efficiencies in all cases. By equating formulas (20) and (26) the value of $\frac{C}{T}$, where the two methods of design give the same efficiency, may be obtained.

For greater values of $\frac{C}{T}$ the spacing denoted by r_1 is to be used, and for less the spacing denoted by r should be used to obtain the highest efficiency. The above formulas may be equated by using the values for R as given by formulas (18) and (25) respectively and $R_a = r_1^{m-1}$

and writing r_1 in terms of r, for by definition $r_1 = r + 1$. Performing this operation, it is found that where two rows of rivets are used, *i.e.*, where $m = 2$ and $\frac{C}{T} = 1.666$, the symmetrical spacing of rivets may be secured by moving A either to position B in Fig. 44 or to position B in Fig. 45, without effecting the efficiency of the joint. If $\frac{C}{T}$ is greater than 1.666, then the arrangement in Fig. 45 should be used to obtain the highest efficiency. If $\frac{C}{T}$ is less than 1.666, the arrangement in Fig. 44 should be used. Tables VIII and IX show the arrangement to be chosen for the highest-efficiency joints of the two types. For symmetrically spaced rivets and pitches increasing from row to row as shown in Figs. 44 and 45, Table VIII indicates which arrangement gives the highest joint efficiency, dependent on the ratio $\frac{C}{T}$.

TABLE VIII.—RIVET ARRANGEMENT FOR HIGHEST JOINT EFFICIENCY WHERE PITCHES ARE CONSTANTLY WIDENED FROM ROW TO ROW

Number of rows of rivets in joint	Use arrangement of rivets illustrated in Fig. 44 if $\frac{C}{T}$ is less than	Use arrangement of rivets in either Figs. 44 or 45 when $\frac{C}{T}$ has a value of	Use arrangement of rivets illustrated in Fig. 45 if $\frac{C}{T}$ is over
2	1.6666	1.6666	1.6666
3	1.7857	1.7857	1.7857
4	1.8718	1.8718	1.8718
5	1.9274	1.9274	1.9274

For symmetrically spaced rivets with mixed pitches, *i.e.*, where two rows of evenly spaced rivets are used and the remaining rows have constantly widening pitches, Table IX indicates which arrangement gives the highest efficiency.

The values for Table IX are obtained by equating formulas (23) and (29), using the values of R as given by formulas (21) and (28) respectively and value of $R_b = r_1^m$. It is necessary to write r_1 in terms of r as was done in calculating values for Table VIII.

TABLE IX.—RIVET ARRANGEMENT FOR HIGHEST JOINT EFFICIENCY USING MIXED PITCHES

Number of rows of evenly spaced rivets	Number of rows of rivets with widening pitches	Total number of rows of rivets	Use arrangement of rivets for widening rows as illustrated in Fig. 44 if $\frac{C}{T}$ is less than	Use arrangement of rivets for widening rows as illustrated in either Figs. 44 or 45 when $\frac{C}{T}$ has a value of	Use arrangement of rivets for widening pitches as illustrated in Fig. 45 when $\frac{C}{T}$ has a value over
2	1	3	1.6000	1.6000	1.6000
2	2	4	1.7500	1.7500	1.7500
2	3	5	1.8528	1.8528	1.8528

While Tables VIII and IX have been given to make the subject of maximum-efficiency joints complete, the improvement due to having the rivets closely spaced, as in Fig. 44, determines that this latter arrangement is the one that should be adopted for almost every case.

Sawtooth Joints.—An arrangement of rivets commonly used where the calking edge of the outer strap is to be serrated, or what is usually termed the "sawtooth" joint, is illustrated in Fig. 52. Where this arrangement of rivets is to be used, for a joint of the highest efficiency it is necessary for the relation between the plate thickness and rivet diameter to be maintained as given in formulas (7) and (8), and the pitch must be such that the strength of the net section of the plate between the rivet holes in the outer row will equal the crushing strength of the plate in front of all the rivets in a unit section length of the joint. As there are nine rivets in a unit section of this joint, the above conditions as to pitch would be met when

$9Ctd = (P - d)tT$, or $P = d\left(9\frac{C}{T} + 1\right)$, which is seen to be the same as formula (11). The efficiency of such a joint would be the pitch less the rivet-hole diameter divided by the pitch, that is,

$$\frac{d\left(9\frac{C}{T} + 1\right) - d}{d\left(9\frac{C}{T} + 1\right)} \text{ or } E = \frac{9C}{9C + T},$$

which is the same as formula (17).

Thickness of Straps.—As far as theoretical strength is concerned, single-riveted joints or those in which the rivets in all the rows are spaced alike, if provided with a strap or with straps, the strap thickness or combined strap thickness need not be more than equal to the plate thickness to prevent the strength of the straps from interfering with the joint efficiency, provided the tensile strength of the strap material is at least equal to that of the plate. The efficiency due to the failure either of the straps or of the plate, in cases where the strap thickness or the combined strap thickness equals the plate thickness, would be the same in all such joints, no matter in what way they may tend to fail.

There is no fixed rule for strap thickness for joints in which the rivets are spaced differently in the successive rows and where the straps are of equal width, but formulas may be written to cover the requirements for strap thickness for joints of maximum efficiency. For maximum efficiency joints, where the spacing of the rivets is increased from row to row, the strap thickness required is usually greater than for the highest efficiency joints where the rivets are symmetrically spaced, the number of rows of rivets in each type of joint being the same. However, in joints where the rivets are symmetrically spaced and the arrangement is such that the highest efficiency is not obtained, the strap thickness required may be greater than for a joint of maximum efficiency of the same number of rows of rivets.

The only way to be positive that the straps, where of equal width and for a joint in which the rivets are spaced wider apart in the successive rows, are of the proper thickness, is to test their thickness by formula (30). With joints of maximum efficiency where the straps are of unequal widths, it is necessary for the inner straps to be at least equal to the plate in thickness, in order that the strap thickness shall not interfere with the strength of the joint. Joints of maximum efficiency are those where the rivets tend to crush the plate, and if the inner straps are of less thickness than the plate, the straps would tend to crush at the outer rows where the rivets are in single shear, instead of the plate crushing at these rivets.

Since the net section of the straps between the rivet holes on the inner row of rivets on all commercial joints where the pitch of rivets is widened from row to row is the weakest method of failure for the straps, a general statement as to the strap thickness required for all such joints would be: The thickness of each strap of a double-strap joint must be equal to or greater than one-half the plate thickness times the ratio $\frac{E}{E_1}$, where E_1 is the ratio obtained by dividing the net section between the rivet holes on the inner row by the pitch length of that row and where E is the true joint efficiency. Denoting the strap thickness by t_1, the equation $2t_1E_1T = tET$ must be fulfilled when the strength of the straps on a double-strap joint is equal to the strength of the joint by the method of failure determining its efficiency. Solving the equation for t_1 results in

$$t_1 = \frac{0.5tE}{E_1} \tag{30}$$

In maximum-efficiency joints where the rivets are pitched wider apart in each succeeding row, it will be remembered that the efficiency of the first row considered as a single-riveted joint was $\frac{C}{C+T}$, which would represent the value of E_1 in the above equation; also that the efficiency of such a joint of maximum efficiency would be $\frac{P-d}{P}$. Therefore, formula (30) would become

$$t_1 = \frac{0.5t(P-d)(C+T)}{CP} \tag{31}$$

Since the value of E in formula (30) can never equal 100 per cent., and the value of E_1 can never be lower than 50 per cent. for a joint of maximum efficiency unless the tensile strength of the plate is more than its crushing strength, the strap thickness required for a double-strap butt joint of maximum efficiency can never be equal to the plate thickness. Since the tensile strength is much lower than the crushing strength, and the joint efficiency is several per cent. below the

limit of 100 per cent., the strap thicknesses required for double-strap butt joints of maximum efficiency is less than the plate thickness. Table X is calculated on the assumed values of C = 95,000 lb., and T = 55,000 lb. per square inch. Under these conditions the maximum strap thickness that would be required for any number of rows of rivets that might be employed is less than $0.8t$, and in general this relation between the plate thickness and strap thickness will insure that the straps are of sufficient thickness to prevent interference with the strength of the joint as calculated in the usual way. The table shows the strap thickness required for a double-strap joint of maximum efficiency, where both straps are of the same width, given in terms of plate thickness. Where the straps are not of equal widths, the thickness of the inner strap must at least equal the plate thickness for maximum-efficiency joints.

TABLE X.—STRAP THICKNESSES FOR BUTT-STRAP JOINTS OF MAXIMUM EFFICIENCY

Number of rows of rivets in joint, or values of m	For maximum-efficiency joints with equal-width straps in which T = 55,000 lb. and C = 95,000 lb., and where constantly widening pitches for rivets are employed, the strap thickness, t_1, should be equal to or greater than the values given below, which are in terms of plate thickness
2	$0.683t$
3	$0.751t$
4	$0.777t$
5	$0.785t$
20	$0.7895t$

When the value of T increases, the strap thickness required is greater, and where T decreases the strap thickness required is less, as will be seen from formula (31). As has been stated before, the strap thickness for joints with symmetrically spaced rivets may be required greater than for joints of maximum efficiency of the same number of rows of rivets, although over the usual range of pitches that might be employed the strap thickness for joints with symmetrically spaced rivets will be less than required for similar joints of maximum efficiency.

In joints of the highest efficiency with straps of equal width where the spacing of the rivets is symmetrical but changes in each row, the number of rivets in the innermost row will be r^{m-1}, where m is the number of rows of rivets in the joint. Therefore, the value of E_1 will be $\frac{P - dr^{m-1}}{P}$. Since the value of E in such a joint is $\frac{P-d}{P}$, the minimum strap thickness will be (see formula 30)

$$\frac{\frac{0.5t(P-d)}{P}}{\frac{P-dr^{m-1}}{P}} \text{ or } t_1 = \frac{0.5t(P-d)}{P-dr^{m-1}} \tag{32}$$

In the case where mixed pitches are used and the straps are of equal width, and the ratio r is employed to determine the spacing of the rivets in the outer rows of widening pitches, the number of rivets in a unit section on the inner rows of evenly spaced rivets, will be r^m, wher m is the number of rows of rivets of widening pitches. The value of E_1 in this case will be $\frac{P-dr^m}{P}$, and the strap thickness required will be

$$\frac{\frac{0.5t(P-d)}{P}}{\frac{P-dr^{m}}{P}} \text{ or } t_1 = \frac{0.5t(P-d)}{P-dr^{m}} \tag{33}$$

It will be noted that in the case of mixed pitches the number of rows of evenly spaced rivets does not effect the required strap thickness.

Strap Thickness for Commercial Joints.—It should be understood that the formulas given to determine the minimum strap thickness required for joints of maximum efficiency, where equal-width straps are employed, refer only to the thickness required to give the necessary theoretical strength to prevent interference with the strength of the joint when calculated in the usual way, but these limiting thicknesses should not be used in commercial boiler joints, as straps of such thickness would not in all cases permit of proper calking. It should also be noted that the strap thickness for joints with symmetrically

spaced rivets and of the highest efficiency, is less than required for similar joints of lower efficiency.

FORMULAS FOR MAXIMUM EFFICIENCY JOINTS OR THOSE OF THE HIGHEST EFFICIENCY USING SYMMETRICALLY SPACED RIVETS

The various formuals that have been derived in connection with maximum-efficiency joints are grouped here in order that they may be readily referred to.

For double-strap butt joints, where the straps are of equal width, the thickness of plate t must be such that

$$t = < \frac{0.7854d(2S)}{C} \tag{7}$$

For lap or single-strap joints, or for double-strap joints where the straps are of unequal widths, the thickness of plate t must be such that

$$t = < \frac{0.7854dS}{C} \tag{7a}$$

For double-strap butt joints where the straps are of equal width, the rivet-hole diameter d must be such that

$$d = > \frac{tC}{0.7854(2S)} \tag{8}$$

For lap or single-strap joints, or for double-strap joints where the straps are of unequal widths, the rivet-hole diameter d must be such that

$$d = > \frac{tC}{0.7854S} \tag{8a}$$

In the following illustrations descriptive of the kinds of joints to which the formulas apply (Figs. 47 to 52), it will be noted that both straps are shown the full width of the joints, except the one illustrating the usual type of sawtooth joint. Any of these joints may have the edges of the outer straps cut back between the rivets as in the case of the sawtooth joint, or the outer straps may be reduced in width any desired amount as long as the relation required between rivet-hole diameters and plate thickness is maintained and the inner straps are made as thick or thicker than the plate.

Joints of Maximum Efficiency.—Joints like Fig. 47, in which the rivets in all rows are of the same pitch. The theoretical minimum strap thickness is $t_1 = 0.5t$.

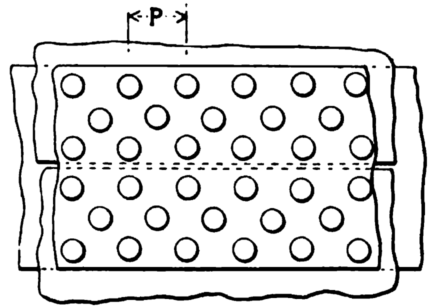


FIG. 47.

The value of n in the figure is 3.

$$P = \frac{C}{T} dn + d \tag{11}$$

$$E = \frac{RC}{RC + T} \tag{17}$$

$$E = \frac{P - d}{P}$$

$$R = n \tag{14}$$

Joints like Fig. 48, in which the rivets in each row are spaced wider apart than in the preceding row. Theoretical minimum strap thickness is

$$t_1 = \frac{0.5t(P - d)(C + T)}{CP} \tag{31}$$

The value of m in the figure is 3.

$$P = d\left(\frac{C}{T} + 1\right)^m \tag{12}$$

$$E = \frac{RC}{RC + T} \tag{17}$$

$$E = \frac{P - d}{P}$$

$$R = \frac{\left(\frac{C}{T} + 1\right)^m - 1}{\frac{C}{T}} \tag{15}$$

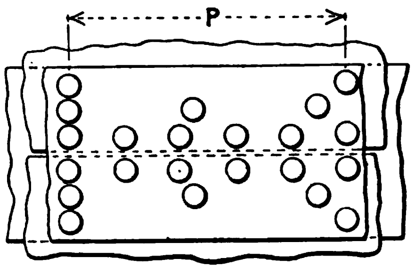


FIG. 48.

Joints like Fig. 49 in which mixed pitches are used, there being n rows of evenly spaced rivets and m rows with widening pitches, but not symmetrically spaced except where $\frac{C}{T}$ happens to be a whole number. Theoretical minimum strap thickness is

$$t_1 = \frac{0.5t(P - d)}{P - d\left(\frac{C}{T} + 1\right)^m}$$

The value of n is 2 and the value of m is 2 in the figure.

$$P = d\left(\frac{C}{T}n + 1\right)\left(\frac{C}{T} + 1\right)^m \tag{13}$$

$$E = \frac{RC}{RC + T} \tag{17}$$

$$E = \frac{P - d}{P}$$

$$R = \frac{\left(\frac{C}{T}n + 1\right)\left(\frac{C}{T} + 1\right)^m - 1}{\frac{C}{T}} \tag{16}$$

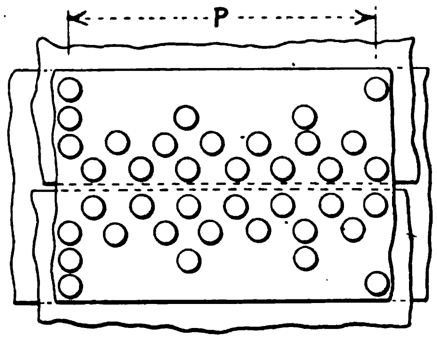


FIG. 49.

JOINTS OF HIGHEST EFFICIENCY SYMMETRICALLY SPACED RIVETS

Joints like Fig. 50 in which the rivets in each succeeding row are spaced wider apart than in the preceding row and the ratio of spacing r is the next whole number below $\left(\frac{C}{T} + 1\right)$. Theoretical minimum strap thickness is

$$t_1 = \frac{0.5t(P - d)}{P - dr^{m-1}}$$

The value of r is 2 and the value of m is 3 in the figure.

$$P = d\left[\left(\frac{r^m - 1}{r - 1}\right)\frac{C}{T} + 1\right] \tag{19}$$

$$E = \frac{RC}{RC + T} \tag{20}$$

$$E = \frac{P - d}{P}$$

$$R = \frac{r^m - 1}{r - 1} \tag{18}$$

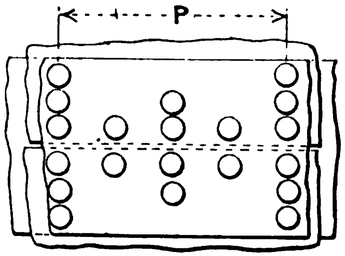


FIG. 50.

Joints like Fig. 51, in which mixed pitches are used and the ratio of spacing r is the next whole number below $\left(\frac{C}{T} + 1\right)$. Theoretical minimum strap thickness is

$$t_1 = \frac{0.5t(P - d)}{P - dr^m}$$

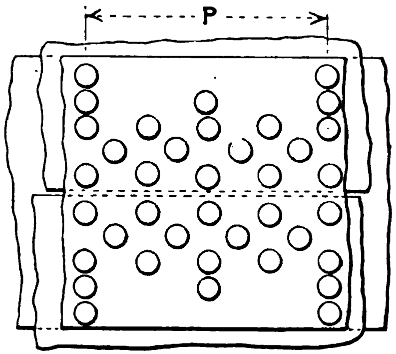


FIG. 51.

The value of r is 2, the value of n is 3, and the value of m is 2 in the figure.

$$P = d\left[\left(\frac{r^m - 1}{r - 1} + nr^m\right)\frac{C}{T} + 1\right] \tag{22}$$

$$E = \frac{RC}{RC + T} \tag{23}$$

$$E = \frac{P - d}{P}$$

$$R = \frac{r^m - 1}{r - 1} + nr^m \tag{21}$$

The usual arrangement of rivets applicable to the sawtooth type of joint (Fig. 52), and where the rivets are spaced to give the highest efficiency. Theoretical minimum strap thickness is

$$t_1 = \frac{0.5t(P - d)}{P - 3d}$$

$$P = d\left(9\frac{C}{T} + 1\right) \qquad E = \frac{9C}{9C + T} \qquad E = \frac{P - d}{P} \qquad R = 9$$

NOTE.—Where rivets are symmetrically spaced it will be found easiest to make a sketch of the joint under consideration and count the

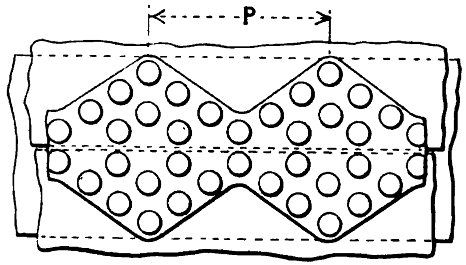


FIG. 52.

number of rivets in a unit section, rather than figure the number by the formulas given here. After the number of rivets in a unit section is known, the efficiency may be obtained by the aid of the formulas.

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